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NASCAP-2K VERSION 4.2 USER'S MANUAL

V.A. Davis, et al.

**Leidos, Inc.
10260 Campus Point Drive, Mailstop C4
San Diego, CA 92121**

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Technical Report

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14. ABSTRACT

Nascap-2k is a spacecraft charging and plasma interactions code designed to be used by spacecraft designers, aerospace and materials engineers, and space plasma environments experts to study the effects of both the natural and spacecraft-generated plasma environments on spacecraft systems.

This document describes the user interface, how to use the code, and some of the physical assumptions of the computation models included in the code.

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Nascap-2k, Spacecraft Charging, Space Environment

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SUMMARY

Nascap-2k is a spacecraft charging and plasma interactions code designed to be used by spacecraft designers, aerospace and materials engineers, and space plasma environments experts to study the effects of both the natural and spacecraft-generated plasma environment on spacecraft systems. Survival in the plasma environment is a concern for virtually all Earth orbiting satellites, be they in low Earth orbit (LEO), geostationary orbit (GEO), polar orbit, or others, and for interplanetary and planetary missions as well. Increased power requirements have pushed spacecraft subsystem design parameters, such as solar array voltage and power, to higher values than ever before, while demand for resources, especially in the commercial telecommunications industry, has resulted in the need for longer mission lifetimes. Additionally, electric propulsion critical to the success of many exploration as well as commercial missions, produces a high-energy, high-density plasma, the effects of which can result in serious erosion and contamination problems for spacecraft surface coatings and for sensitive instruments. As a result, design strategies for mitigation of deleterious plasma effects require rethinking to meet these changing requirements and more severe environments.

Nascap-2k was developed as part of a program sponsored jointly by the Air Force Research Laboratory and by the NASA Space Environments and Effects (SEE) Program at Marshall Space Flight Center.

This manual is designed to be used in several different ways: as a help reference to interface menus, field variables, and actions; as a guide to performing specific tasks such as defining the type of problem to be solved or the particular environment to use; as a guide to start-to-finish performance of typical problems such as charging in a tenuous plasma; and as general documentation of the physics and engineering models implemented in *Nascap-2k*. *Nascap-2k Scientific Documentation* describes the physical and numerical models used in the surface charging, potential solution and particle tracking portions of the code.

This document is comprised of the following general parts:

Part I, Overview, is a general overview of *Nascap-2k* containing information on its capabilities and approach, the various modules that comprise the tool and the high-level architecture that joins them, the units used, computational and file size limitations, and installation requirements and procedure.

Part II, Using *Nascap-2k*, provides the details of how to use the code. This part is further divided into several sections that address opening a project, the menus, the tabs, and the output files.

- Section 5 describes the basic approach to using *Nascap-2k*.
- Section 6 describes how to get started by creating a new project or opening an existing project.
- Section 7 describes the various menu items available, including view and material definition.
- Section 8 describes the options for specifying the type of problem.

- Sections 9 and 10 describe the requirements to be aware of when creating an object (detail on object creation is in the *Object Toolkit User's Manual*) and how to grid the space surrounding an object.
- Sections 11 through 15 describe the various physical and computational parameters used by *Nascap-2k*. These sections also discuss the physics models used in the computations.
- Section 16 describes the process of generating and executing the script that directs the desired calculations.
- Section 17 describes how to view results either numerically, as a time-dependent plot, or as a three-dimensional graphical representation of surface and volume values.

Part III contains four start-to-finish examples that illustrate the use of *Nascap-2k*'s computational capabilities: charging in a geostationary orbit, current collection in low-Earth orbit, calculation of wake effects, and calculation involving a time-dependent plasma environment.

These three primary parts are followed by a glossary of terms, some common "gotchas" and Frequently Asked Questions (FAQs), and a set of appendices containing information for the advanced user and the just plain curious.

I OVERVIEW

1 Need for *Nascap-2k*

Designers of spacecraft for government, commercial, and research purposes require advanced modeling capabilities to guide the design of satellites that can survive and operate properly in the natural environment. In the past, computer modeling of flight experiments (such as SCATHA (Spacecraft Charging at High Altitude),[1] the SPEAR (Space Power Experiment Aboard Rockets) [2,3] series, and CHAWS (Charging Hazards and Wake Studies)[4]) demonstrated excellent ability to predict both steady-state and dynamic interactions between high-voltage spacecraft and the ambient plasma. This ability was also extended to inherently dynamic problems involving three-dimensional space charge sheath formation, current flow in the quasi-neutral presheath, breakdown phenomena, plasma kinetics, ionization processes, and the effect of unsteady processes on spacecraft charging.

Nascap-2k builds on these capabilities, giving the spacecraft designer much-improved modeling capabilities by taking advantage of a greater understanding of the pertinent phenomena, employing more advanced algorithms, and implementing a state-of-the-art user interface, including three-dimensional post-processing graphics.

Nascap-2k was developed a as part of a program sponsored jointly by the Air Force Research Laboratory (now at Kirtland Air Force Base) and by NASA's Space Environments and Effects (SEE) Program (at Marshall Space Flight Center).

2 What is *Nascap-2k*?

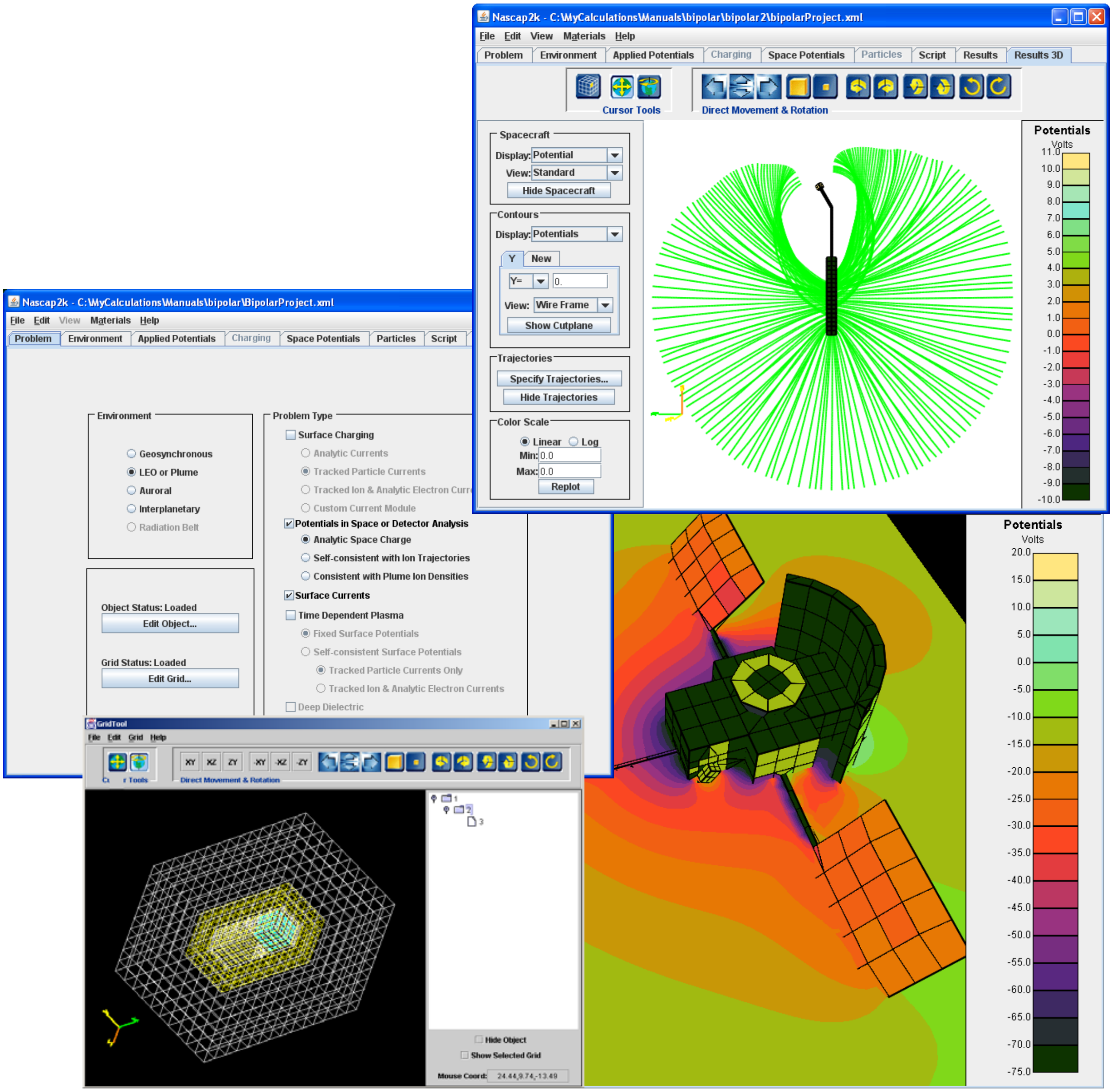
Nascap-2k is an interactive toolkit for studying plasma interactions with realistic spacecraft models in three dimensions. *Nascap-2k* is designed for use by spacecraft design engineers, spacecraft charging researchers, and aerospace engineering students. *Nascap-2k* also enables plasma-interactions specialists to perform realistic analyses with direct application to engineering problems.

The *Nascap-2k* interface employs an index-tab metaphor; several of these tabs are shown in Figure 1. The graphical user interface is designed to help less experienced users easily solve moderately complex plasma-interactions problems.

The core capabilities of *Nascap-2k* are as follows:

- Define spacecraft surfaces and geometry and the structure of the computational space surrounding the spacecraft.
- Solve for time-dependent potentials on spacecraft surfaces.
- Solve the electrostatic potential around the object, with flexible boundary conditions on the object and with space-charge computed either fully by particles, fully analytically, or in a hybrid manner.
- Generate, track, and otherwise process particles of various species, represented as macroparticles in the computational space.

- View surface potentials, space potentials, particle trajectories, and time-dependent potentials and currents.



Nascap2k - C:\MyCalculations\Manuals\bipolar\bipolar2\bipolarProject.xml

Spacecraft
Display: Potential
View: Standard

Contours
Display: Potentials
Y= 0.
View: Wire Frame

Color Scale
● Linear ○ Log
Min: 0.0
Max: 0.0

Nascap2k - C:\MyCalculations\Manuals\bipolar\BipolarProject.xml

Environment
○ Geosynchronous
● LEO or Plume
○ Auroral
○ Interplanetary
○ Radiation Belt

Problem Type
□ Surface Charging
○ Analytic Currents
● Tracked Particle Currents
○ Tracked Ion & Analytic Electron Curr
○ Custom Current Module
☑ Potentials in Space or Detector Analysis
● Analytic Space Charge
○ Self-consistent with Ion Trajectories
○ Consistent with Plume Ion Densities
☑ Surface Currents
□ Time Dependent Plasma
● Fixed Surface Potentials
○ Self-consistent Surface Potentials
● Tracked Particle Currents Only
○ Tracked Ion & Analytic Electron Currents
□ Deep Dielectric

Object Status: Loaded
Grid Status: Loaded

GridTool
□ Hide Object
□ Show Selected Grid
Mouse Coord: 24.44,9.74,-13.49

Figure 1. Selected Views of the *Nascap-2k* User Interface

Nascap-2k Scientific Documentation describes the physics and numeric models used in the surface charging, potential solution and particle tracking portions of the code.

Figure 2 shows an overview of the *Nascap-2k* structure. There are three main programs: *Nascap-2k*, *Object Toolkit*, and *GridTool*. *Object Toolkit* and *GridTool* can be invoked either as separate programs or from the main *Nascap-2k* user interface.

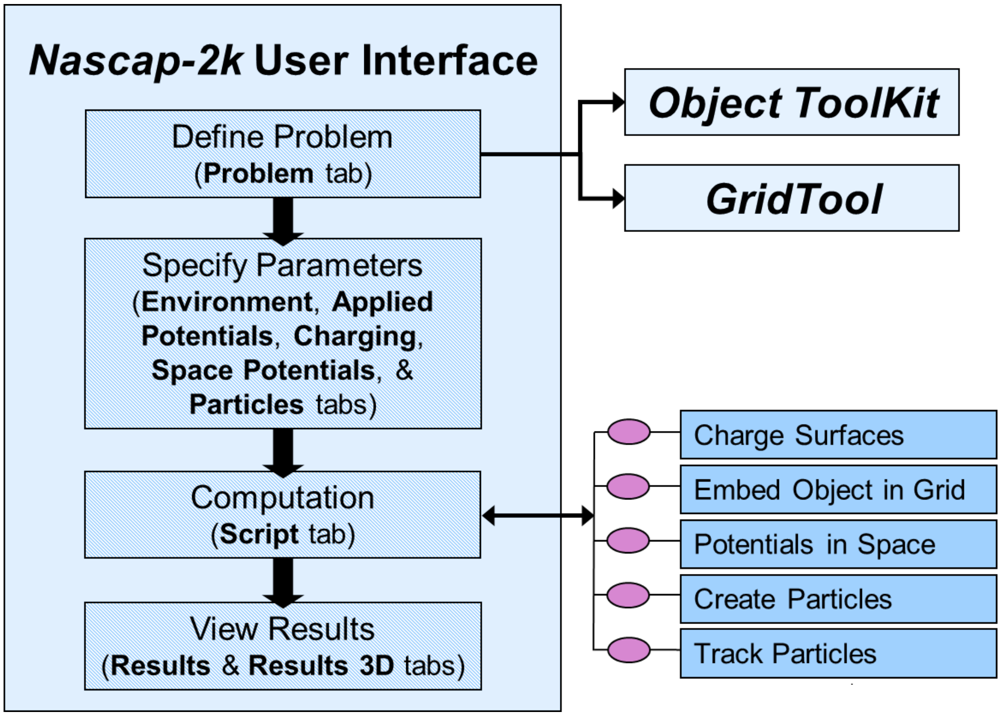


Figure 2. *Nascap-2k* Structure

Object Toolkit is a three-dimensional object generator tailor-made for spacecraft modeling. It is used to create finite-element representations of spacecraft surfaces for *Nascap-2k* (and other environmental interactions computer codes, such as *EPIC* (*Electric Propulsion Interactions Code*)).[5] It also has materials editing capability and can import objects from standard finite-element preprocessors such as *PATRAN*. In this way, the spacecraft geometry can be realistically represented, and existing finite-element models of spacecraft constructed for other purposes can be adapted for use in *Nascap-2k*. *Object Toolkit* output (in eXtensible Markup Language (XML)) contains the recipe for re-creating/reassembling the object, object definition by nodes and elements, and material definitions. *Object Toolkit* is described in Section 9, and more fully in the *Object Toolkit User's Manual*[6].

The computational space around the spacecraft is constructed interactively using the *GridTool* module. Arbitrarily nested subdivision allows resolution of important object features while including a large amount of space around the spacecraft. *GridTool* is described in Section 10.

The main *Nascap-2k* user interface uses an index-tab metaphor, and contains tabs for problem selection, initial conditions, parameter specification, script writing, time-dependent results analysis, and two- and three-dimensional displays of surface potentials and fields.

The kind of problem is specified on the **Problem** tab. The choices made on this tab tailor the rest of the interface's appearance. The various choices regarding initial conditions, environment, and computational parameters are available on subsequent tabs. Advanced parameters that are useful only to a limited number of users are found on dialog boxes that are accessed by clicking "Advanced" buttons on the various tabs.

The *Nascap-2k* computational engines are accessed through the **Script** tab. The five computational modules are **Charge Surfaces**, **Embed Object in Grid**, **Potentials in Space**, **Create Particles**, and **Track Particles**. The script can be run either within the GUI or from the standalone executable N2kScriptRunner.

Nascap-2k calculates surface charging in tenuous plasma environments, such as geosynchronous Earth orbit (GEO) and interplanetary (Solar Wind) environments, using the Boundary Element Method[7] (BEM). The Boundary Element Method facilitates calculation of surface electric fields (which limit the emission of photoelectrons and secondary electrons) without the need to grid up the space surrounding the spacecraft. It also enables *Nascap-2k* to anticipate electric field changes due to surface charging, resulting in a smoother and more stable charging simulation.

Nascap-2k uses a high-order, finite-element representation for the electrostatic potential that ensures electric fields are strictly continuous throughout space. The electrostatic potential solver[8] uses a finite element/conjugate gradient technique to solve for the potentials and fields on the spacecraft surface and throughout the surrounding space. Space charge density models presently include Laplacian, Linear, Non-linear, Frozen Ions, Consistent with Ion Density, Full PIC (Particle in Cell), and Hybrid PIC (appropriate to the several microsecond timescale response to a negative pulse). The input file defining the initial conditions and computational parameters for the potential solver is generated through the user interface.

Particle tracking is used to study sheath currents, to study detector response, or to generate space charge evolution for dynamic calculations. *Nascap-2k* generates macroparticles (each of which represents a collection of particles) at either a sheath boundary, the problem boundary, at user-specified locations, or throughout all space. Particles are tracked for a specified amount of time, with the timestep automatically subdivided at each step of each particle to maintain accuracy. The current to each surface element of the spacecraft is recorded for further processing. The input files defining the initial conditions and computational parameters for both particle creation and tracking are generated through the user interface.

The **Results** tab of the *Nascap-2k* user interface is used to obtain numerical values and time histories of potentials and surface currents. The **Results 3D** tab is used to generate graphical output illustrating such quantities as surface potentials, space potentials, particle positions, and particle trajectories. Contour levels and other plotting attributes are modified through the user interface.

The computational modules of *Nascap-2k* use a database manager. The database manager is a library of routines capable of making large arrays of information contained in disk files accessible to computational modules. It features a programmer-friendly language for defining data types and for retrieving and storing data, and an API accessible through C++, Fortran, or Java. This strategy enables *Nascap-2k* to be operable on, and portable among, modern high-power workstations, which have proven to be more cost effective than supercomputers for this type of code development and analysis.

The user interface is written in Java, the science modules are written in C++ and Fortran, and the utility routines are written in C. All information is stored in the multi-file database or as XML. The modules communicate using XML files, keyword text input files, direct subroutine calls (Dynamic Link Library (DLL) import/export), Java Native Interface (JNI) subroutine calls, and the proprietary database. XML files and text input files can be manually edited with a text editor or XML editor.

2.1 Units

The *Nascap-2k* user interface specifies the units of all input parameters. In general, *Nascap-2k* operates internally in the SI (Systeme International) or MKS system of units. Electrostatic potentials are internally stored in volts, and electric fields in volts per meter. Magnetic fields are always in tesla (webers per square meter). Particle energy or plasma temperature is usually in electron volts. Charge density in coulombs per cubic meter is often divided by the permittivity of free space (ε_0), so that it has the units of volts per square meter.

2.2 Limits

The maximum values for various parameters are shown in Table 1.

Table 1. *Nascap-2k* Limits

Quantity	Limit
Characters in prefix name	80
Surface elements	4095
Nodes	4095
Conductors	25
Materials	999
Time Steps	Unlimited
Particle Types (species)	99
Grids	50
Grid nodes per grid	10^8
Macroparticles per particle type	3×10^8
Special elements	16393
Additional points/special element	100
Centroids per special element	70
Triangles/special element	150
Macroparticles per volume element	1000

The spacecraft model is described by a finite-element representation of surface elements and nodes. Each surface element has a conductor index and a material name. Building an object is described in Section 9.

In the database, a separate particle type is created for each species used in a calculation and for each species tracked for visualization.

The solution of potentials in space or particle tracking requires gridding of the space external to the object. Section 10 describes the construction of grid systems. A grid system consists of a main grid and up to 49 subgrids. The number of nodes in each grid is the product of one plus the number of grid units in each direction: (NX+1)(NY+1)(NZ+1).

Volume elements that are not empty or completely filled by the object or contained within a subgrid are special elements. The **Embed Object in Grid** computational module produces finite-element matrices for special elements that couple surface element potentials and fields to those on volume nodes. Subgridding should be used to divide up special elements that are too complex to be easily resolved (i.e., too many points, centroids, or triangles).

3 Formatting Conventions

Table 2 lists the formatting conventions used in this manual. Italic font is also used for emphasis.

Table 2. Formatting Conventions

Text Style	Meaning
Italics	Names of software, variable portion of filenames and input
Boldface	Names of menus, dialog boxes, tabs, script commands, and computational modules
"Quotation Marks"	Text on interface, including menu items, text box labels, etc.
Lucida Sans Font	Filenames, folder names, web addresses
`Monotype Font`	Large quantities of text that represent computer output

4 Installation

4.1 Requirements

- Computer:
  - Pentium 4 processor or higher, 512 MB memory or higher
  - Available hard drive space: at least 1 GB
- Operating System:
  - Supported:
    - Windows Vista, Windows 7
  - Not supported:
    - Windows 98, Windows 98SE, Windows ME, Windows NT4, Windows 2000, Windows XP, Lindows, Linux, Macintosh, UNIX
- Video Display:
  - 1024×768 or higher resolution
  - Color set to 32 bit.
- Note:
  - Only members of the Administrators Group for the computer (and Computer Administrators) can install software.
  - We strongly recommend that all updates from **http://windowsupdate.microsoft.com** be installed.
  - *Object Toolkit* and *GridTool* can be run on other Java platforms (e.g. Linux or Solaris), but database access is unavailable.

4.2 *Nascap-2k* Installation

To install the 64-bit version of *Nascap-2k*, open **Setup.exe** in the x64 folder on the installation disk. To install the 32-bit version, open Setup.exe in the x86 folder on the installation disk. The *Nascap-2k* user interface, the auxiliary programs *Object Toolkit* and *GridTool*, and several DLLs, along with documentation and example files, are installed. The various files that are installed are listed in Appendix A. Of particular note is the folder **Nascap-2k/Materials** containing files of material properties measured by Utah State University.

Nascap-2k versions 4.1 and 4.2 have a new database that allows larger problems to be run. Projects created using earlier versions of *Nascap-2k* can still be used; however, the results saved in the database will not be accessible. To examine data generated by earlier versions of *Nascap-2k* the earlier version of the software will need to be used.

Nascap-2k 4.2 and earlier versions may be simultaneously installed, as long as they are installed in separate folders.

4.3 Java Installation

Nascap-2k 4.2 requires the Java 2 Standard Edition 7.0 (J2SE 7.0) runtime environment (version 1.7.0 or higher), including the Java3D extension (version 1.5.1 or higher). The *Nascap-2k* installer does not automatically install Java or Java3D.

Before Installing Java

Before a user installs Java, we strongly recommend that the user first go to "Control Panel | Add or Remove Programs" and remove any Java 3D versions that appear. Then remove any versions of Java 2 SDK and/or Java 2 Runtime Environment.

Java (J2SE)

Either the Java runtime environment (JRE) or the larger developer kit (JDK) can be installed. Java 7 or higher is required. The released version of this code was tested with Java SE 7 update 25. The runtime environment is included on the *Nascap-2k* installation disk in the **Java Installs** folder. To install, open **jre-7u67-windows-i586.exe** (for 32 bit) or **7u67-windows-x64.exe** (for 64 bit). In addition, both are available from **http://www.oracle.com/technetwork/java/javase/downloads/index.html**.

Both 32-bit and 64-bit versions of *Nascap-2k* are available. The appropriate version of Java is required. Note that the 32-bit (i586) version of Java can coexist with the 64-bit version on Windows.

Java3D

Java3D is needed to display the active three-dimensional images in *Nascap-2k*. The code does not run without it. The latest version is 1.5.2 and is available on the install disk and from **http://www.softpedia.com/progDownload/Java-3D-Download-162937.html.**

To install, open **j3d-1_5_2-windows-i586.exe** (for 32 bit) or **j3d-1_5_2-windows-amd64.exe** (for 64 bit).

Make sure that Java3D is installed into the correct copy of the jre and/or jdk. (This usually happens by default on Windows, but has been known to fail, particularly on dual-boot machines.)

On some computers, it is necessary to copy the files in **C:\Program Files\Java\Java3D\1.5.2\lib\ext** to **C:\Program Files\Java\jre7\lib\ext** and the files in **C:\Program Files\Java\Java3D\1.5.2\bin** to **C:\Program Files\Java\jre7\bin** (and the equivalent in the 32-bit **\Program Files (x86)** directories). (These paths may be different on your computer and for different versions of Java.) Administrator privileges are generally needed to alter the Java directory. *This may need to be done every time Java is updated.*

II USING *NASCAP-2K*

5 Basic Approach

The *Nascap-2k* user interface is designed to help less-experienced users easily solve moderately complex plasma-interactions problems, while also allowing plasma interactions specialists to perform realistic analyses with direct application to engineering problems.

To perform a *Nascap-2k* calculation, proceed as follows:

1. Create the geometry, specify the surface materials, and define any new materials using *Object Toolkit*.
2. Open a new *Nascap-2k* project.
3. Load the object into *Nascap-2k.*
4. Specify the problem by making selections on the **Problem** tab and defining a grid (if needed) using *GridTool*.
5. Review all the values on the available tabs, changing the specifications and adding parameters as needed.
6. On the **Script** tab, build the default script. Examine it to make sure it carries out the appropriate procedures using the desired parameters. Edit the script if necessary. For complex problems it is generally appropriate to divide the problem into steps.
7. Run the script.
8. View the results using the **Results** tab, the **Results 3D** tab, and the output files as appropriate.
9. Make adjustments and repeat or continue.

The best way to become familiar with *Nascap-2k* is to step through either the **Spacecraft Charging in a Tenuous Plasma** (Section 18) or the **Current Collection in a Low-Earth-Orbit Plasma** (Section 19) example in **Part III, Examples**. The appropriate sections of **Part II, Using *Nascap-2k*** can be consulted while performing the example calculations to become familiar with the variety of options available and their appropriate use.

When the code behaves unexpectedly, consult the **Common Gotchas and Frequently Asked Questions** section.

6 Creating or Opening a Project

The opening screen of *Nascap-2k* (Figure 3) provides the user with the choice of creating a new project (Figure 3, left side) or opening an existing project (Figure 3, right side). Each project is identified by a "*prefix*" used to name the files created and optionally used as a directory in which the files are stored. Appendix A describes the files. To re-create a project (e.g., to make a copy or re-create a corrupted database) requires the ***prefix*Project.xml** and ***prefix*Object.xml** files along with the optional ***prefix*.grd**, ***prefix*Plume.xml**, and ***prefix*Photo.xml** files.

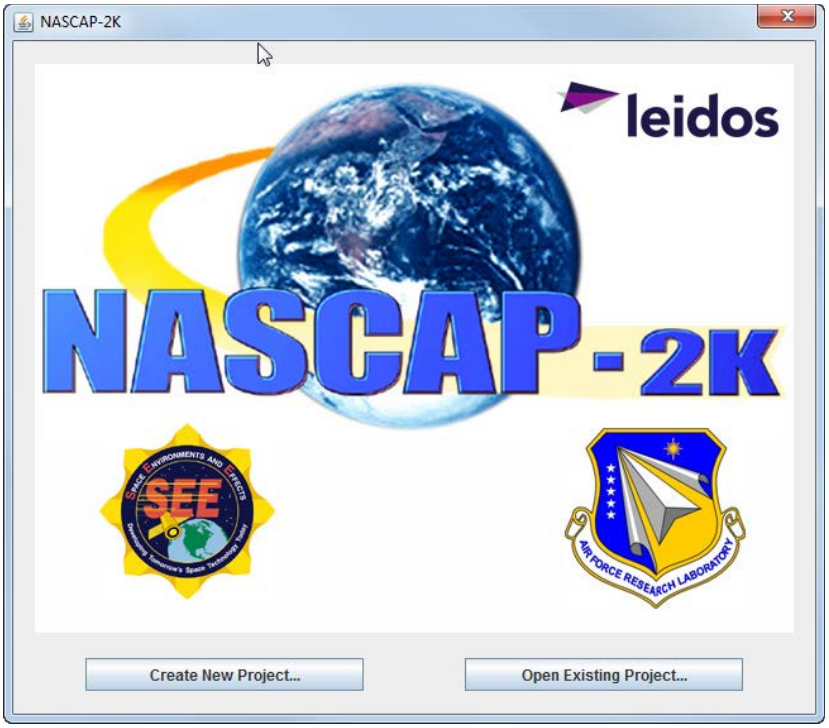
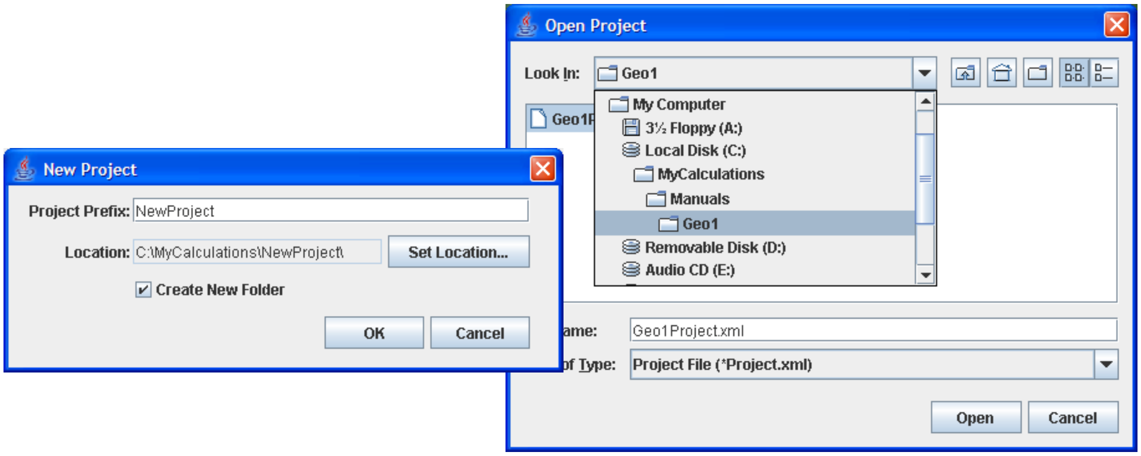


Figure 3. Opening Screen of the *Nascap-2k* User Interface



Look In: Geo1

ame: Geo1Project.xml

of Type: Project File (*Project.xml)

Project Prefix: NewProject

Location: C:\MyCalculations\NewProject\

☑ Create New Folder

Figure 4. Opening a New (left) or Existing (right) Project in *Nascap-2k*

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7 Main Menus

The main menus in *Nascap-2k* allow the user to perform a number of top-level, project-related functions such as loading and saving the project. The **View** menu is used to change the appearance of the display area on the **Results 3D** tab. The **Materials** menu allows users to edit the material properties. For additional information on material properties see Section 13.4.

Note: *When a material is changed from a conductor to an insulator or from an insulator to a conductor,* Nascap-2k *should be closed and restarted*.

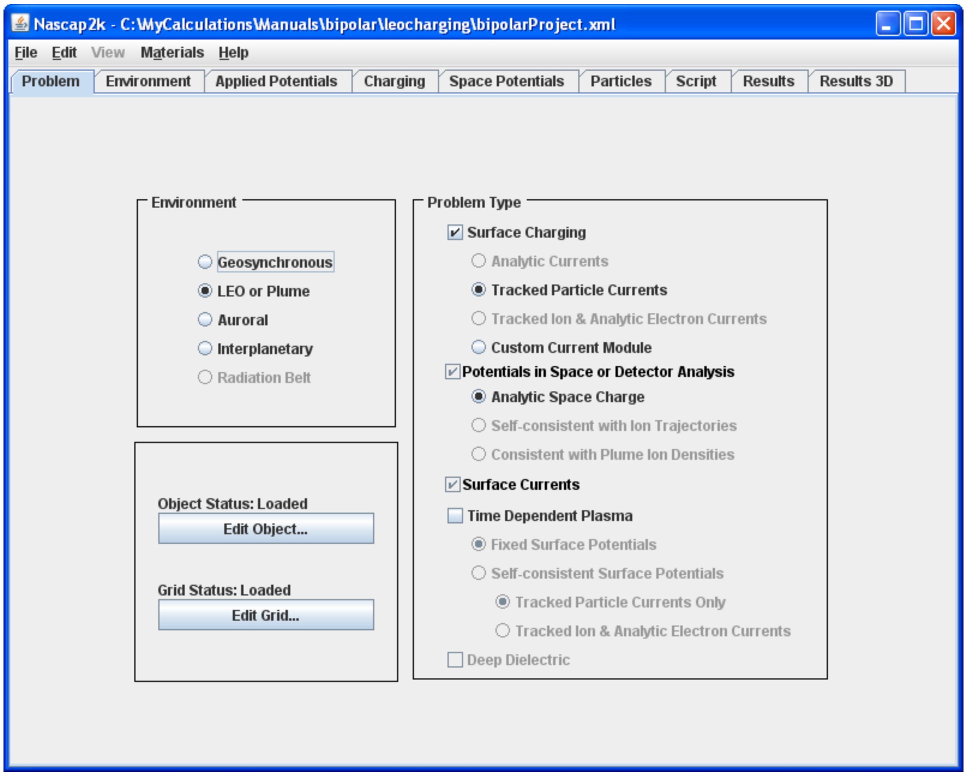
The *Nascap-2k* online **Help** menu provides basic information and descriptions of the parameters that appear on the interface. Table 3 describes the main menu options.

Table 3. *Nascap-2k* Menu Options

Nascap-2k MAIN MENUS	
PARAMETER	**DEFINITION**
File	
New Project	Create a new project.
Open Project	Open existing project file.
Save Project	Save existing project file.
Save Project As	Save new or existing project file under a new name.
Load Object	Import existing *Object Toolkit* object file into current project for the computation of the resulting potentials. An object must be loaded before the options on the **Problem** tab are enabled.
Load Plume	Import a plume map file into current project for the computation of the resulting potentials. See Section 14.
Load Script	Import a saved script file into current project. See Section 16.
Import SEE Handbook Materials File	Import material definitions from a file in the format saved by *SEE Interactive Spacecraft Charging Handbook*. See Section 13.4.
Export Script…	Save the current script to a file. See Section 16.
Export Tecplot…	Save the current object and surface potentials to a Tecplot data file.
Exit	Exit the *Nascap-2k* user interface.
View	Enabled when **Results 3D** tab is displayed.
From X, Y, Z, -X, -Y, -Z Axis	Reorient view of object so that it is from specified coordinate axis.
From Sun	Reorient view of object so that it is from the sun direction.
From RAM	Reorient view of object so that it is from the direction the object is headed.
From Specified Direction	Reorient view of object so that it is from a user specified direction.
Timestep to Display	Display results for the specified timestep.
Display Special Components	Turn display of special components defined in *Object Toolkit* off or on.
Set Background Color	Set background color of 3D display area to black or white.
Set Outline Color	Set color of lines outlining surface elements to black or white or do not display lines (off).
Color Scale Direction	Set color scale so that white or black is most positive.
Rescale View	Scale view of object to fit within display area.
Perspective	Turn perspective adjustment on or off.
Mouse Position	Show or hide pop-up window that displays the position of the mouse in meters from the center of the grid. Useful for determining an appropriate cut plane position or tracking limit. Turns off perspective.
Legend Font Size	Increase or decrease font size used in legend on **Results 3D** tab.
Edit	Not implemented.
Materials	Edit properties of existing materials, including photoemission spectra. Materials are defined in *Object Toolkit*. See Section 13.4.
Help	
Nascap-2k Help	Display online help file.
About *Nascap-2k*	Display *Nascap-2k* version, copyright, and contacts information.

8 Defining the Problem (Problem Tab)

Figure 5 illustrates the options in the **Problem** tab. Table 4 lists the parameter definitions.



Environment

○ Geosynchronous
● LEO or Plume
○ Auroral
○ Interplanetary
○ Radiation Belt

Object Status: Loaded

Grid Status: Loaded

Problem Type

☑ Surface Charging
○ Analytic Currents
● Tracked Particle Currents
○ Tracked Ion & Analytic Electron Currents
○ Custom Current Module
☑ Potentials in Space or Detector Analysis
● Analytic Space Charge
○ Self-consistent with Ion Trajectories
○ Consistent with Plume Ion Densities
☑ Surface Currents
□ Time Dependent Plasma
● Fixed Surface Potentials
○ Self-consistent Surface Potentials
● Tracked Particle Currents Only
○ Tracked Ion & Analytic Electron Currents
□ Deep Dielectric

Figure 5. Problem Tab in *Nascap-2k*

The available values for "Environment" and "Problem Type" depend on the availability of an object and a grid. The object, if not already loaded, is loaded using the "Load Object" choice on the **File** menu. The grid is automatically loaded if a ***prefix*.grd** file is present.

Some "Problem Types" are not available for some choices of "Environment."

Choices of "Environment" and "Problem Type" govern the available and default options on subsequent tabs and the contents of automatically generated scripts. This functionality has been tailored to facilitate running certain standard problems, such as those provided in this manual as examples. The ability to edit the actual script and its parameters either within the user interface or externally using a text or XML editor, together with the ability to edit the generated text input files for the various modules, allows advanced users to extend *Nascap-2k*'s capabilities beyond the standard problems while continuing to work within the user interface.

The **Problem** tab also contains buttons that can be used to launch *Object Toolkit* ("Edit Object…") and *GridTool* ("Edit Grid…").

Table 4. Input Parameters for the Problem Tab

PROBLEM		
PARAMETER		**DEFINITION**
Environment		Specification of spacecraft environment type.
Geosynchronous		Geosynchronous Earth orbit (altitude ~36,000 km) substorm environment: High-energy isotropic tenuous plasma.
LEO or Plume		Low Earth orbit (altitude 100–1000 km) or plume environment: Cold, dense isotropic plasma.
Auroral		Auroral (altitude >100 km): Low energy (<1 eV) electrons and streaming ions along with high-energy precipitating electrons.
Interplanetary		Solar Wind: Tenuous, moderate energy (~10 eV) electrons and streaming (~1 keV) protons.
Radiation Belt		(Altitude >1000 km near the equator, lower at high latitude.) High-energy electrons of up to a few MeV and protons of up to several hundred MeV energy. (Not yet implemented.)
Problem Type		Specifications for type of calculation and model to be used.
Surface Charging		Charging of surfaces due to the space environment.
	Analytic Currents	Surface currents calculated analytically using formulation appropriate to specified environment. (LEO charging assumes flowing Maxwellian, appropriate only for Debye length comparable to or longer than the object size.)
	Tracked Particle Currents	Surface currents taken from particle tracking results. (LEO only.)
	Tracked Ion &Analytic Electron Currents	Electron surface currents calculated analytically using formulation appropriate to specified environment and ion currents taken from particle tracking results.
Potentials in Space or Detector Analysis		Electrostatic potentials and particle tracking in the space surrounding the spacecraft. (Requires a grid.)
	Analytic Space Charge	Use analytic formulae for charge density distribution. (All environments.)
	Self-consistent with Ion Trajectories	Solve iteratively until electric potentials and ion charge densities are consistent with governing equation(s). (LEO and Auroral only. Not available with surface charging.)
	Consistent with Plume Ion Densities	Use ion densities imported from a plume map file with or without a contribution from *Nascap-2k* calculated charge exchange particles. See Appendix E. (Not available with surface charging.)
Surface Currents		Compute surface currents using particle tracking. (LEO and Auroral only. Requires a grid.)
Time Dependent Plasma		Dynamic plasma calculation using particle tracking. (LEO only. Requires a grid.)
	Fixed Surface Potentials	Use surface potentials set as specified on **Applied Potentials** tab.
	Self-consistent Surface Potentials	Determine surface potentials using tracked currents only or tracked currents plus an analytic model of electron currents.
Deep Dielectric		Fields due to charge deposited (e.g., by radiation-belt electrons) within dielectric layers. (Not yet implemented.)
Object Status		Indicates whether a geometric model has been imported into the project.
Edit Object		Launch *Object Toolkit* to create or edit a geometric model. Model is automatically loaded into the project on return from *Object Toolkit*.
Grid Status		Indicates the existence of a grid (.grd) file for the project.
Edit Grid		Launch *GridTool* to create or edit a spatial mesh surrounding the model. Grid automatically loaded (if saved) on return from *GridTool*.

9 Creating a Spacecraft Model

The first step in a *Nascap-2k* project is to construct a geometrical model of the spacecraft. Object definition for *Nascap-2k* is performed using *Object Toolkit.* The use of *Object Toolkit* is fully described in the *Object Toolkit User's Manual*.

Object Toolkit is used to create finite-element representations of spacecraft surfaces. It also has materials editing capability, and can import a finite-element representation from a *PATRAN* neutral file or a *NX I-DEAS* TMG ASCII VUFF file. The XML output file contains the finite-element specification of the object surfaces, the recipe for re-creating/reassembling the object, and the properties of the default and used materials. *Object Toolkit* can be customized to create geometric models for other analysis codes. Presently it is also used to define spacecraft for *EPIC*.[5]

The user interface for *Object Toolkit* is shown in Figure 6.

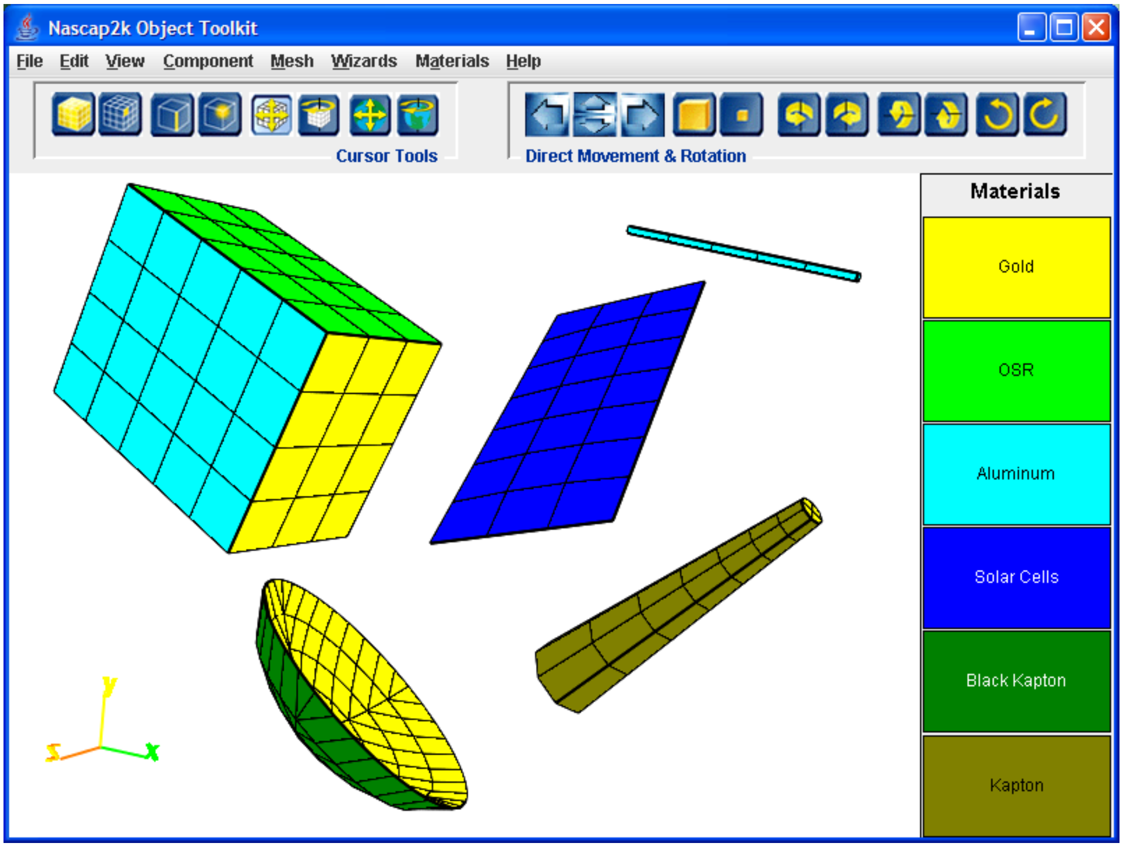


Figure 6. *Object Toolkit* Screen Showing Standard Components

9.1 Object Requirements

Nascap-2k performs analyses for potentials and electric fields on surface elements and in space using the Boundary Element and Finite Element Methods. The objects (i.e., spacecraft models) defined using *Object Toolkit* and the grids defined using *GridTool* determine the geometry of *Nascap-2k* problems. The surface and spatial geometry must conform not only to the strict requirements of the Boundary Element and Finite Element Methods, but also to *Nascap-2k* specific requirements, as well as to standards that are not strictly required, but which are needed to avoid pathological results. Note that other *Object Toolkit* client applications may use different computational methods, resulting in very different object definition requirements.

9.1.1 General

Objects are defined by points in space (called “Nodes”) and elemental surfaces (called “Surface Elements” or “Elements”), which are defined using the Nodes as vertices. All physical quantities and results focus on the surface elements. Thus, each surface element is assigned “attributes” such as material name, conductor number, and initial potential. A calculation assigns physical results such as electrostatic potential, electric field, and incident current density to each surface element. In calculating these results, each surface element is assumed to consist of either exposed metal or metal with an exposed thin dielectric coating. This, as well as the plasma interactions of the surface element, is determined by properties associated with the material name.

9.1.2 Material Name Attributes

Each surface element has a string attribute indicating material name. Properties associated with the material name determine whether the surface element is metal or dielectric coating, the conductivity and capacitance (if a coating), and the electron emission stimulated by incident electrons, protons, or sunlight. Note that material names are case-insensitive in *Nascap-2k*.

9.1.3 Conductor Number Attributes

Each surface element has an integer (1–25) attribute indicating “Conductor Number.” These assignments may be used for purely diagnostic purposes or as a basis for internal spacecraft circuitry. Conductor number 1 is considered “spacecraft ground.” Higher numbered conductors are biased relative to ground or floating.

9.1.4 Closed Surfaces

The assembled surface elements are required to form one or more disjoint closed surfaces in three-dimensional space. Equivalently, any point in three-dimensional space must be unambiguously identifiable as being inside the object, external to the object, or (if ambiguous) on the object surface.

9.1.5 Surface Elements

Individual surface elements may be either triangles or quadrilaterals. A quadrilateral element should be as nearly planar as possible (i.e., should not be grossly non-planar). In general, quadrilaterals are preferred to triangles. Each element is described by three or four vertices listed in counterclockwise order (as viewed from exterior space). If possible, the aspect ratio (length/width) of the element should be no greater than two. Also (if possible) the area of an element should not be grossly different from that of its neighbors. For calculations that use a grid, element dimensions should be within about a factor of two of the local grid spacing.

9.1.6 Resolution

The geometric resolution of the calculation is determined by the surface element size (and the grid spacing for gridded calculations). The geometric model should have the overall shape of the object (spacecraft) of interest, approximately correct conductor and insulator areas, and represent the distribution of insulators and conductors across the surfaces. Typical models have from several hundred to about 2000 surface elements. An excessive number of surface elements slows the calculation and, in some cases, reduces the accuracy of the result. The best resolution is typically a few percent of the overall object size, and it is generally impractical to resolve features smaller than a fraction of a percent. So for a commercial communications spacecraft with dimensions in the 10 m range, the resolution should be on the order of 10 cm, with coarser resolution on large, uninteresting or conductive areas, and finer resolution on areas of potential interest. While zones need not be perfectly square, high aspect ratio zones (greater than 3:1) should be avoided as much as possible.

Large flat areas should generally be 5 to 9 elements across in the short direction. Additional elements can be used to resolve fine electric field structure from complex geometry, and should have at least 2 to 3 spatial zones across the feature. Large panels (e.g., solar panels) should be modeled with thickness a substantial fraction of the surface resolution, even if the actual panels are much thinner. Conductor patterns may be used on solar panels to mimic the string layout on a gross scale.

Beyond these general guidelines, the model geometry should be driven by the question of interest. Features of particular concern should be well represented. It is sometimes necessary to separately model fine structure (such as a probe, antenna, or detector), either with a separate "coupon" model of the detailed structure, or with the detailed model mounted on a large brick, cylinder, or other simple structure representing the remainder of the spacecraft.

9.1.7 Compatibility (Edge)

An "Edge" is the line joining an adjacent pair of vertices of a surface element. The compatibility requirement states that each edge must be traversed exactly once in each direction (i.e., in the forward direction by the surface element in which we first found it, and in the reverse direction by a neighboring element). Equivalently, each edge must have exactly one element on its right and exactly one on its left. Edges that violate the compatibility requirement are drawn in red in *Object Toolkit*.

The reason for this requirement is that its violation leads to discontinuous surface potentials. For example, in Figure 7, point B, as a vertex for one of the dark-blue surface elements, may be assigned a potential different from the potential that would be obtained by linear interpolation between the ends of the edge of the light-blue element that goes from A to C. We would then have a sudden jump in potential across the edge.

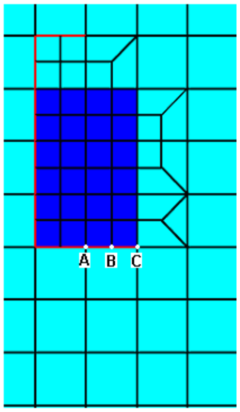


Figure 7. Example Showing Incompatible Edges and their Repair

To repair this problem, (1) subdivide the offending light-blue element (as at top left); (2) delete the three offending small elements; and (3) construct two new elements from the free edges of the small element to the free long edges, forming the pattern seen to the right of the dark-blue area.

9.1.8 Special Objects (Ion Thrusters, Neutralizers, Magnetic Dipoles)

The locations and directions of ion thrusters and neutralizers used in a “Consistent with Plume Ion Densities” calculation are defined in *Object Toolkit*. The properties of the thrusters and neutralizers, as well as the background neutral density, are defined in the imported plume map file. (See Appendix A.) Presently, only one plume map file (and thus one type of thruster) is allowed. A thruster is a source of energetic ions, neutrals that effuse uniformly through its grids, and (optionally or initially) charge exchange ions. Charge exchange ion densities may be taken from the plume map file or generated and tracked self-consistently in *Nascap-2k*. Thrusters may be temporarily turned on or off or gimbaled from the *Nascap-2k* interface. A neutralizer is a source of neutrals that may undergo charge exchange with the energetic ions. *Nascap-2k* automatically attenuates the main beam ion densities (as specified in the plume map file) due to charge exchange interaction with the background neutral density.

The locations (meters relative to object center) and moments (A m^2) of spacecraft-generated magnetic dipoles are defined in *Object Toolkit*. The resulting magnetic field is calculated (from the dipole values stored in the database) and used when computing particle trajectories. *Nascap-2k* reads new or revised dipole moments and locations on startup or object load, and saves them to the database when the Project is saved, either explicitly or due to running a script.

Note that thrusters, neutralizers, and dipoles are defined by their locations, and are not associated with object surfaces.

9.1.9 Emitters, Detectors, and Injection Points

Emitters, Detectors, and Injection Points (for Transverse Surface Current calculations) are defined in *Object Toolkit*. These properties are defined by assigning an Emitter, Detector, or Injection Point name to a surface element. Injection Points require no additional properties. The properties of Emitters and Detectors are defined in *Object Toolkit* and can be modified on the **Particles** tab and **Particle Advanced** dialog.

10 Creating a Grid System Around the Spacecraft

A system of arbitrarily nested cubic grids is used to calculate electrostatic potentials and fields, store charge densities, and track charged particles in the space external to the spacecraft. Electrostatic potential and electric field are defined at each grid point, leading to strictly continuous electric fields. (More commonly used finite-element systems only define potential at each grid point. This leads to continuous potentials, but it also leads to electric fields that are discontinuous across grid cell boundaries.)

10.1 *GridTool*

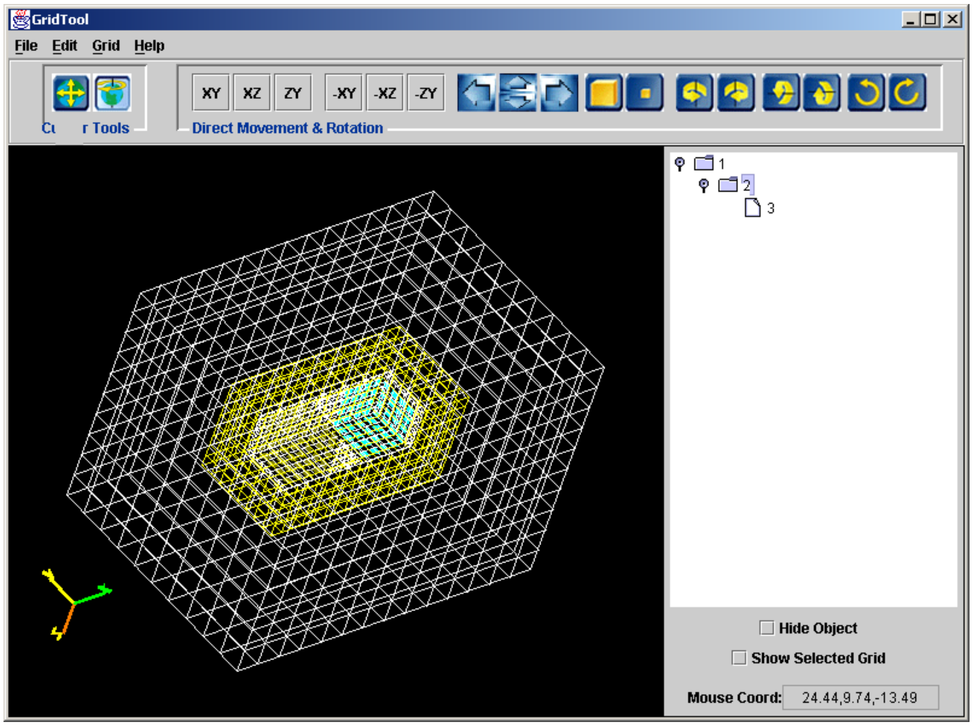
Nascap-2k's *GridTool* is used to define an arbitrarily nested grid structure about the object. *GridTool* allows the user to define a grid structure for an object created by *Object Toolkit*. A grid is needed to compute potentials in space, to track particles, or to compute wake structure.

GridTool has the following capabilities:

- Create and modify a primary grid around an object.
- Add and modify a child grid.
- Delete a grid and all its child grids.
- Import an existing grid structure.
- Graphically display the current grid structure.

GridTool can be launched either directly or by clicking the "Edit Grid" button on *Nascap-2k*'s **Problem** tab. The **File** menu can be used to open an existing database or an *Object Toolkit* geometric model. An existing grid definition can also be read in. If no grid definition exists, the grid definition process starts by selecting "New Primary Grid" from the **Grid** menu, and then varying the parameters presented in the grid definition dialog.

A simple example of a 3-level grid is shown in Figure 8.



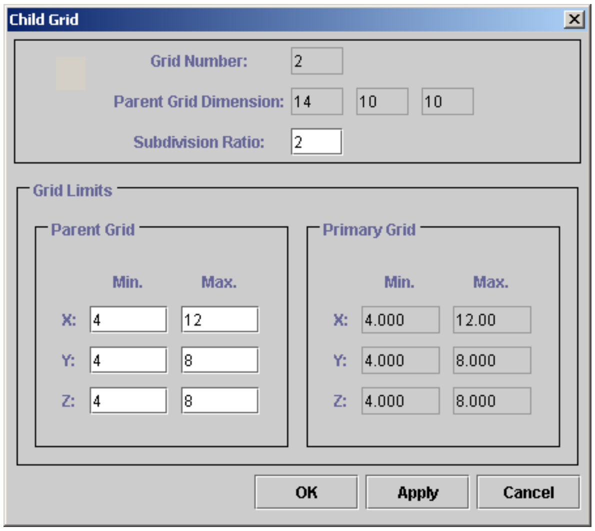
☐ Hide Object

☐ Show Selected Grid

Mouse Coord: 24.44,9.74,-13.49

Figure 8. Grid in Space Generated Using *GridTool*

Using the Tree View on the right, the user can select the parent grid or any of the child grids to modify or delete, and/or add a new child grid. In Figure 8, the second-level child grid has been chosen for modification. The dialog box for the definition of a child grid is shown in Figure 9. The user specifies the subdivision ratio and the minimum and maximum indices within the parent grid coordinate system.



Grid Number: 2

Parent Grid Dimension: 14 10 10

Subdivision Ratio: 2

Grid Limits

	Parent Grid Min.	Parent Grid Max.		Primary Grid Min.	Primary Grid Max.
X:	4	12	X:	4.000	12.00
Y:	4	8	Y:	4.000	8.000
Z:	4	8	Z:	4.000	8.000

Figure 9. Child Grid Dialog Box for Defining or Modifying a Child Grid in *GridTool*

Grid files are saved with the extension “.grd.” The file format is described in Appendix A.

10.2 *GridTool* Menu Options

GridTool's menu options and movement/orientation tools and their usage are listed in Table 5.

10.3 Grid Requirements

GridTool is used to construct a grid system about an object. The outermost or primary grid encloses the entire computational space and should have all its boundaries sufficiently far from the object that the near-object fields are not perturbed. *GridTool* is then used to add nested child grids to achieve adequate resolution near the object and in other regions of interest. See Sections 19, 20, and 21 for examples.

10.3.1 Parameters Defining a Grid

A grid is defined by its extent in the three coordinate directions (NX, NY, NZ), its subdivision ratio (relative to its parent) and the resultant grid spacing, and its origin in its parent and the resultant origin in the primary grid. The number of grid points in each direction is greater by one than the number of grid elements. Positions in grid coordinates range from 1 to NX+1 (etc.), so that the center of the grid is located at ((NX+2)/2, (NY+2)/2, (NZ+2)/2).

10.3.2 Grid Size

It is recommended that the extents for each individual grid—NX, NY, NZ—be even numbers, leading to odd numbers of grid points in each direction, NX+1, NY+1, NZ+1. Each dimension must be at least 2, with typical values in the range of 16 to 40. There is no set maximum, but dimensions in excess of a few hundred are not recommended.

10.3.3 Object Placement

GridTool allows the position of the object to be adjusted within the grid structure. By default, the center of the object's bounding box coincides with the center of the primary grid. In general, the object placement and main grid spacing should be chosen so that spacecraft components are not coincident with grid planes with two exceptions. Flat panels, such as solar arrays, are best placed to coincide with grid planes (so as not to subdivide volume elements). In addition, booms are best placed so that they lie along grid lines (so as not to pierce the faces of volume elements). The object position may be adjusted so that low-capacitance objects (e.g., a small instrument on a long boom) lie closer to the grid boundary than high-capacitance objects (e.g., the spacecraft's body or solar panels).

10.3.4 Subdivision Recommendations

It is recommended that the subdivisions in a child grid be a factor of two finer than those of the parent grid. Subdivision by factors of three or four may be used with caution. Subdivision by factors greater than four should be avoided. Sudden changes in resolution can lead to unphysical results.

Table 5. *GridTool* Menu Options

GRIDTOOL MAIN MENU AND MOVEMENT/ORIENTATION TOOLS

PARAMETER	DEFINITION
File	
Open Database	Open existing database file.
Import Object	Import object file (*.xml) created with *Object Toolkit*.
Import Grid	Import existing grid file (*.grd).
Save Grid	Save newly created or modified grid. As the object dimensions are stored in the grid file, the object must be present for the grid file to be valid.
Exit	Exit *GridTool*.
Edit	
Undo/Redo	Not implemented.
Cut	Not implemented.
Copy	Not implemented.
Paste	Not implemented.
View	Enabled when **Results 3D** tab is displayed.
Display special objects	Turn display of special objects defined in *Object Toolkit* off or on. When the object is read by selecting “Open Database” on the **File** menu special objects never appear.
Set background color	Set background color of 3D display area to black or white.
Set outline color	Set color of lines outlining surface elements to black or white or do not display lines (off).
Grid	
New Primary Grid	Create a new primary grid.
Add Outer Grid	Create a new outer grid with twice the linear dimension of the current primary grid, and modify the existing grid structure accordingly.
New Child Grid	Create a new child of the selected grid. (Enabled when a grid is selected in the right-side panel.)
Delete Grid	Delete selected grid. (The primary grid cannot be deleted.)
Edit Grid	Edit selected grid. (Enabled when a grid is selected in the right-side panel.)
Move Object	Specify location (meters) of object center relative to grid center. (Requires that an object be present.)
Help	
GridTool Help	View *GridTool* help file.
About *GridTool* Application	Display *GridTool* version, copyright, and contacts information.
View tools	
✥ 🌐	Set Cursor Tools to rotate and translate the view.
XY XZ ZY -XY -XZ -ZY	View from specific direction.
⇦ ⇆ ⇨	Translate Left/Right, Up/Down.
■ ▪	Zoom In/Out.
↶ ↷ ↶ ↷	Rotate about axis.
↺ ↻	In-plane rotation.

10.3.5 Child Grid

A child grid is fully contained within its parent. A child of the primary grid may not touch the primary grid boundary. A child of a non-primary grid may touch the boundary of its parent for the purpose of sharing a boundary plane with a cousin grid. Examples of correct and incorrect subdivision are shown in Figure 10. The left-hand figure shows two child grids properly meeting at a common boundary. The center figure shows two child grids (cousins) properly touching the boundaries of their respective parents for the purpose of sharing a common boundary. The right-hand figure shows two examples of child grids improperly touching their parents' boundaries. In the egregious case (red) the twice-subdivided grid shares a boundary of its parent with the primary grid. In the subtle case (burgundy) the twice-subdivided grid shares a boundary with a coarser grid that is not its parent.

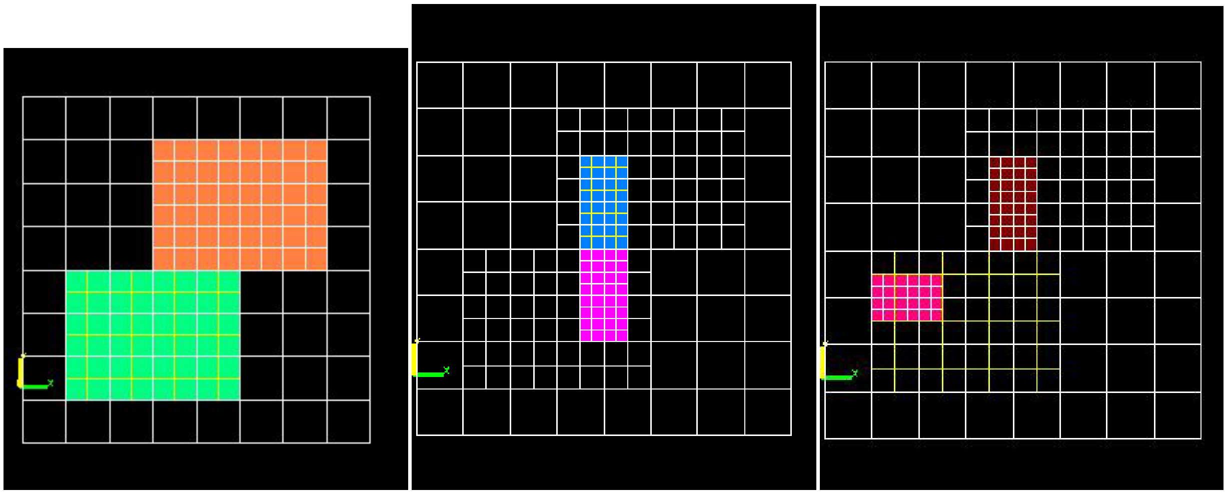


Figure 10. Examples of Correct (Left and Center) and Incorrect (Right) Subdivision

10.3.6 Grid Overlap

Sibling grids (i.e., children of a common parent) may not overlap. However, they may touch (i.e., share a common boundary plane).

10.3.7 Boundary Plane Resolution

The resolution of the boundary between two grids is the coarser (parent) resolution (i.e., the grid points belonging only to the finer grid are assigned values interpolated from the coarser grid). This is necessary to maintain continuity of potentials and electric fields. As an exception, the boundary between two abutting grids of equal mesh spacing is fully resolved.

10.3.8 Grid Resolution

It is recommended that the grid resolution near the object be comparable to the size of the object's surface elements. It is recommended that the grid resolution in the "sheath region" be as few Debye lengths as possible. (Two Debye lengths is ideal, but a few tens of Debye lengths is more common.)

11 Specifying the Environment (Environment Tab)

Presently, *Nascap-2k* supports geosynchronous, low Earth orbit or plume, auroral, and interplanetary environments. Common to all four are the options to specify the local magnetic field vector, the direction toward the sun, the (relative) sun intensity at the location of the spacecraft, and mass, charge, and percent of plasma density for up to one-hundred species of particles. Note that the intent of these differing environment specifications is not to restrict *Nascap-2k* to particular classes of orbits, but to provide the choice of parameters commonly used to describe the plasma environments in those orbits.

11.1 Geosynchronous Earth-Orbit Environment

The tab for definition of a geosynchronous environment is shown in Figure 11. For the geosynchronous environment, four predefined environments are available. These environments are as follows:

- *Worst Case:* The standard NASA "worst-case" charging environment defined in Reference 9.
- *ATS-6:* Double-Maxwellian approximation to an environment once measured by the ATS-6 spacecraft.
- *Sept. 4th 1997:* Double-Maxwellian approximation to an environment measured on the specified day by the Los Alamos Magnetospheric Plasma Analyzer.
- *SCATHA-Mullen1*: Double-Maxwellian approximation to the environment which produced the worst vehicle charging ever measured by SCATHA (April 24, 1979, 0650 UT, as given in Mullen et al, 1981[10]).

The values for the predefined environments are summarized in Table 6. Additionally the user may select "User Defined." "User Defined" environments can be parameterized as Single-Maxwellian, Double-Maxwellian, Kappa, or Measured. The second column available for specifying density and temperature is for cases in which a Double-Maxwellian distribution for electron and/or ions is used.

The differential flux ($m^{-2}\ s^{-1}\ eV^{-1}$) for the Single-Maxwellian, Double-Maxwellian, and Kappa distribution functions are given by the following formulas:

Single Maxwellian
$$F(E) = \sqrt{\frac{e}{2\pi\theta m}}\,\frac{E}{\theta}\,n\exp\left(-\frac{E}{\theta}\right), \tag{1}$$

Double Maxwellian
$$F(E) = \sqrt{\frac{e}{2\pi\theta_1 m}}\,\frac{E}{\theta_1}\,n_1\exp\left(-\frac{E}{\theta_1}\right) + \sqrt{\frac{e}{2\pi\theta_2 m}}\,\frac{E}{\theta_2}\,n_2\exp\left(-\frac{E}{\theta_2}\right), \tag{2}$$

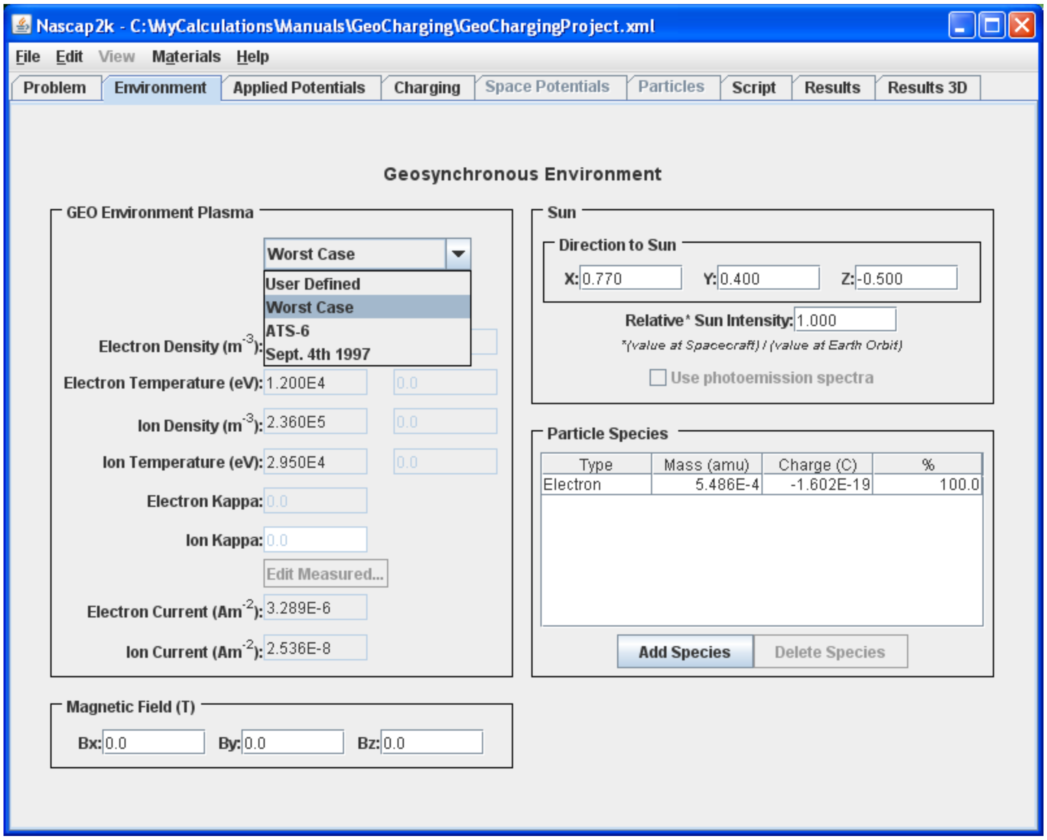
Kappa Distribution
$$F(E) = \sqrt{\frac{e}{2\pi\kappa\theta m}}\,\frac{E}{\kappa\theta}\,n\left(\frac{\Gamma(\kappa+1)}{\Gamma\left(\kappa-\frac{1}{2}\right)}\right)\left(1+\frac{E}{\kappa\theta}\right)^{-\kappa-1} \tag{3}$$

Where n, θ, and, κ are the density, temperature, and kappa parameter, e and m are the electron charge and charged particle mass. A kappa distribution is similar to a Maxwellian, but with a superthermal tail. Kappa must be greater than 1. At large values of kappa (of order 10), the Kappa distribution reduces to a Maxwellian.

The ionic composition is assumed to be 100% H^+.

The lower energy component of a double Maxwellian environment should be specified in the first column.

Table 7 summarizes the list of input parameters for the **Geosynchronous Environment** tab.



Nascap2k - C:\MyCalculations\Manuals\GeoCharging\GeoChargingProject.xml

Geosynchronous Environment

GEO Environment Plasma

Worst Case

Electron Density (m^{-3}):		
Electron Temperature (eV):	1.200E4	0.0
Ion Density (m^{-3}):	2.360E5	0.0
Ion Temperature (eV):	2.950E4	0.0
Electron Kappa:	0.0	
Ion Kappa:	0.0	
Electron Current (Am^{-2}):	3.289E-6	
Ion Current (Am^{-2}):	2.536E-8	

Sun

Direction to Sun

X: 0.770 Y: 0.400 Z: -0.500

Relative* Sun Intensity: 1.000

*(value at Spacecraft) / (value at Earth Orbit)

□ Use photoemission spectra

Particle Species

Type	Mass (amu)	Charge (C)	%
Electron	5.486E-4	-1.602E-19	100.0

Magnetic Field (T)

Bx: 0.0 By: 0.0 Bz: 0.0

Figure 11. The Environment Tab for Studies in a Geosynchronous Plasma

Table 6. Predefined Geosynchronous Charging Environments

	WORST CASE	ATS-6	SEPT. 4TH 1997	SCATHA-MULLEN1
Electron Density (m^{-3})	1.1×10^{6}	1.2×10^{6}	3×10^{5} ; 2×10^{5}	2.3×107; 2×10^{6}
Electron Temperature (eV)	1.2×10^{4}	1.6×10^{4}; 1000	4000; 7000	2.48×10^{4}; 400
Ion Density (m^{-3})	2.4×10^{5}	2.4×10^{5}; 8820	3×10^{5}; 2×10^{5}	1.3×10^{6}; 1.6×10^{6}
Ion Temperature (eV)	2.95×10^{4}	2.95×10^{4}; 111	4000; 7000	2.82×10^{4}; 300
Electron Current (A/m^{2})	3.3×10^{-6}	4.1×10^{-6}	9.6×10^{-7}	9.8×10^{-5}
Ion Current (A/m^{2})	2.5×10^{-8}	2.5×10^{-8}	2.2×10^{-8}	$1.5\times10e^{-7}$
Distribution	Single Maxwellian	Double Maxwellian	Double Maxwellian	Double Maxwellian

Table 7. Input Parameters for the Geosynchronous Environment Tab

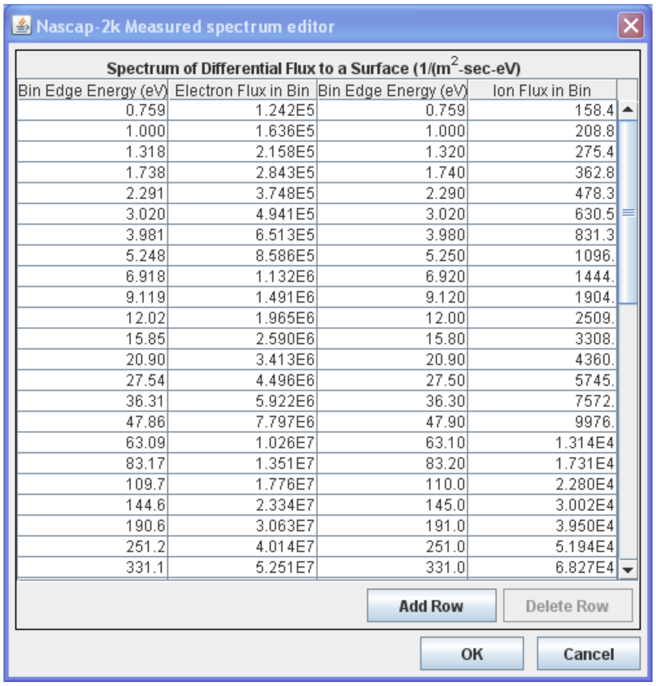
GEOSYNCHRONOUS ENVIRONMENT	
PARAMETER	**DEFINITION**
GEO Environment Plasma	
Drop-down list	Options: User Defined, Worst Case, ATS-6, Sept 4th, 1997, and SCATHA-Mullen1 (see Table 6). Plasma parameters available for editing only if “User Defined” is selected.
Drop-down list (hidden in Figure 11)	Options: Maxwellian, Double Maxwellian, Kappa, Measured. (Some of the following parameters are only available for specific options.)
Electron Density	Number density for the ambient electrons (m^{-3}).
Electron Temperature	Temperature of the ambient electrons (eV).
Ion Density	Number density for the ambient ions (m^{-3}).
Ion Temperature	Temperature of the ambient ions (eV).
Electron Kappa	Kappa parameter for electron distribution.
Ion Kappa	Kappa parameter for ion distribution.
Edit Measured…	Specify tables of values of differential flux as a function of energy.
Electron Current	Electron thermal current (Am^{-2}).
Ion Current	Ion thermal current (Am^{-2}).
Magnetic Field	
Bx, Bx, Bz	Components of the ambient magnetic field vector (tesla).
Sun	
Sun Direction (X, Y, Z)	Direction toward the sun in the spacecraft frame of reference.
Relative Sun Intensity	Ratio of sun intensity at the spacecraft over the 1 AU value.
Use photoemission spectra	See Section 11.5. (Enabled only if at least one material has a photoemission spectrum defined.)
Particle Species	Specification of particle species through their mass, charge, and percentage of the total plasma density. Note that these species are used for particle tracking purposes only.

Using Measured Spectra

It is occasionally desirable to specify the incident electron and ion flux using a table of values. Clicking the “Edit Measured…” button on the **Environment** tab brings up the **Measured**

spectrum editor dialog box. A *Nascap-2k* tabular definition of the incident charged particle spectra consists of a sequence of energy values in electron volts (lower bin boundary energy) and the differential flux in particles per m^2-sec-eV within the energy bin. The electrons and the ions are specified separately. As it is unused (due to unspecified upper bin boundary), the last value in the flux columns should be zero. Figure 12 shows the lower energy portion of a spectrum specification.

Extreme caution should be used when using the "Measured" environment option, as inadequately characterized environments can lead to numeric instabilities or unphysical results.



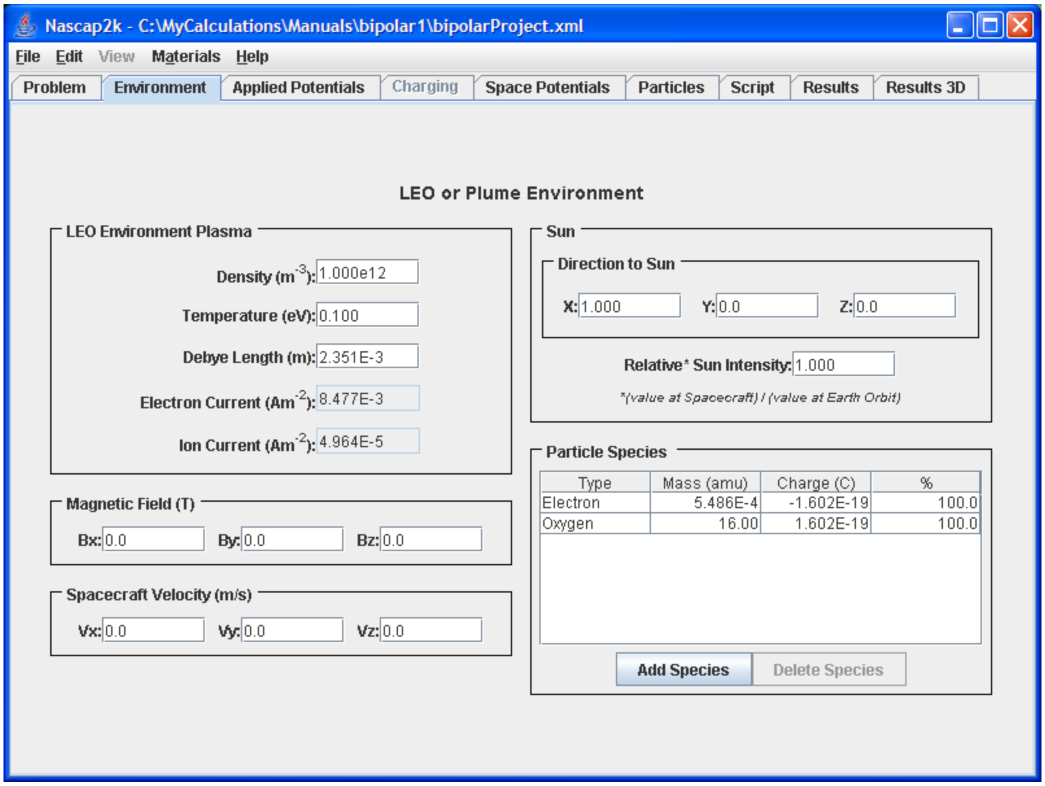
Spectrum of Differential Flux to a Surface (1/(m^2-sec-eV)

Bin Edge Energy (eV)	Electron Flux in Bin	Bin Edge Energy (eV)	Ion Flux in Bin
0.759	1.242E5	0.759	158.4
1.000	1.636E5	1.000	208.8
1.318	2.158E5	1.320	275.4
1.738	2.843E5	1.740	362.8
2.291	3.748E5	2.290	478.3
3.020	4.941E5	3.020	630.5
3.981	6.513E5	3.980	831.3
5.248	8.586E5	5.250	1096.
6.918	1.132E6	6.920	1444.
9.119	1.491E6	9.120	1904.
12.02	1.965E6	12.00	2509.
15.85	2.590E6	15.80	3308.
20.90	3.413E6	20.90	4360.
27.54	4.496E6	27.50	5745.
36.31	5.922E6	36.30	7572.
47.86	7.797E6	47.90	9976.
63.09	1.026E7	63.10	1.314E4
83.17	1.351E7	83.20	1.731E4
109.7	1.776E7	110.0	2.280E4
144.6	2.334E7	145.0	3.002E4
190.6	3.063E7	191.0	3.950E4
251.2	4.014E7	251.0	5.194E4
331.1	5.251E7	331.0	6.827E4

Figure 12. Measured Spectrum Editor Dialog Box

11.2 Low-Earth-Orbit or Plume Environment

The tab for definition of a low Earth orbit or plume environment is shown in Figure 13. The plasma density and temperature are specified. The Debye length is computed from the density and temperature. If the user changes the Debye length, the density is recomputed to be consistent. Both the spacecraft velocity vector and the particle species are specified here. Table 8 summarizes the parameters that appear on the **LEO or Plume Environment** tab.



LEO or Plume Environment

LEO Environment Plasma

Density (m^{-3}): 1.000e12

Temperature (eV): 0.100

Debye Length (m): 2.351E-3

Electron Current (Am^{-2}): 8.477E-3

Ion Current (Am^{-2}): 4.964E-5

Magnetic Field (T)

Bx: 0.0 By: 0.0 Bz: 0.0

Spacecraft Velocity (m/s)

Vx: 0.0 Vy: 0.0 Vz: 0.0

Sun

Direction to Sun

X: 1.000 Y: 0.0 Z: 0.0

Relative* Sun Intensity: 1.000

*(value at Spacecraft) / (value at Earth Orbit)

Particle Species

Type	Mass (amu)	Charge (C)	%
Electron	5.486E-4	-1.602E-19	100.0
Oxygen	16.00	1.602E-19	100.0

Figure 13. The Environment Tab for Studies in a Low-Earth-Orbit or Plume Plasma

Table 8. Input Parameters for the LEO or Plume Environment Tab

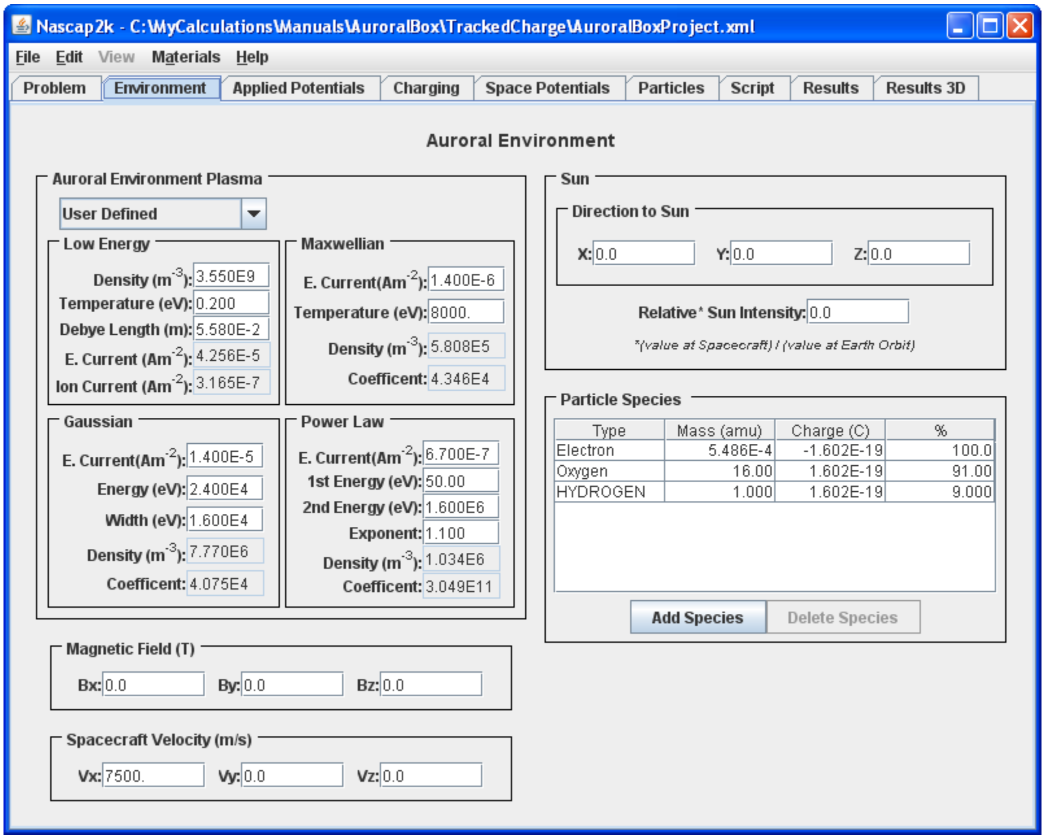
LEO ENVIRONMENT	
PARAMETER	**DEFINITION**
LEO Environment Plasma	
Density	Number density of the ambient plasma (m^{-3}).
Temperature	Temperature of the ambient plasma (eV).
Debye Length	Debye length of the ambient plasma (m).
Electron Current	Electron thermal current (Am^{-2}).
Ion Current	Ion thermal current (Am^{-2}).
Magnetic Field	
Bx, By, Bz	Components of the ambient magnetic field vector (tesla) in the spacecraft frame of reference.
Spacecraft Velocity	
Vx, Vy, Vz	Components of the spacecraft velocity vector (m/s). (Used for computing ram ion and wake effects.)
Sun	
Direction to Sun (X,Y,Z)	Direction toward the sun in the spacecraft frame of reference.
Relative Sun Intensity	Ratio of sun intensity at the spacecraft over the 1 AU value.
Particle Species	Specification of particle species through their mass, charge, and percentage of the total plasma density.

11.3 Auroral Environment

The tab for definition of an auroral environment is shown in Figure 14. The low energy plasma is defined by a Maxwellian with the ion species defined in the “Particle Species” box. The high-energy electrons are defined by a Fontheim[11] distribution. It has three high-energy components, specified by the net current in each component. The Maxwellian component describes a broad electron distribution, the Gaussian component describes the “inverted-V” part of the spectrum, and the Power Law component describes the secondary and backscattered electrons from interactions between the Gaussian beam and the rest of the plasma. The Power Law component only contributes at energies between specified lower and upper cutoffs. The density of each component is calculated based on its current and distribution function and displayed in the dialog. The electron differential flux ($\mathrm{m}^{-2}\ \mathrm{s}^{-1}\ \mathrm{eV}^{-1}$) is specified by

$$\mathrm{Flux}(\mathrm{E}) = \sqrt{\frac{e}{2\pi\theta m_e}}\frac{E}{\theta}n\exp\left(-\frac{E}{\theta}\right) + \pi\zeta_{max}E\exp\left(-\frac{E}{\theta_{max}}\right) + \pi\zeta_{gauss}E\exp\left(-\left(\frac{E_{gauss}-E}{\Delta}\right)^2\right) + \pi\zeta_{power}E^{-\alpha} \qquad (4)$$

where n and θ are the density and temperature of the low-energy ionospheric plasma, e and m_e are the electron charge and mass, and the ζs, θ_{max}, E_{gauss}, Δ, and α are constants. Table 9 summarizes the parameters of the **Auroral Environment** tab.



Auroral Environment

Auroral Environment Plasma: User Defined

Low Energy
Density (m^{-3}): 3.550E9
Temperature (eV): 0.200
Debye Length (m): 5.580E-2
E. Current (Am^{-2}): 4.256E-5
Ion Current (Am^{-2}): 3.165E-7

Maxwellian
E. Current(Am^{-2}): 1.400E-6
Temperature (eV): 8000.
Density (m^{-3}): 5.808E5
Coefficent: 4.346E4

Gaussian
E. Current(Am^{-2}): 1.400E-5
Energy (eV): 2.400E4
Width (eV): 1.600E4
Density (m^{-3}): 7.770E6
Coefficent: 4.075E4

Power Law
E. Current(Am^{-2}): 6.700E-7
1st Energy (eV): 50.00
2nd Energy (eV): 1.600E6
Exponent: 1.100
Density (m^{-3}): 1.034E6
Coefficent: 3.049E11

Magnetic Field (T)
Bx: 0.0 By: 0.0 Bz: 0.0

Spacecraft Velocity (m/s)
Vx: 7500. Vy: 0.0 Vz: 0.0

Sun
Direction to Sun
X: 0.0 Y: 0.0 Z: 0.0

Relative* Sun Intensity: 0.0

*(value at Spacecraft) / (value at Earth Orbit)

Particle Species

Type	Mass (amu)	Charge (C)	%
Electron	5.486E-4	-1.602E-19	100.0
Oxygen	16.00	1.602E-19	91.00
HYDROGEN	1.000	1.602E-19	9.000

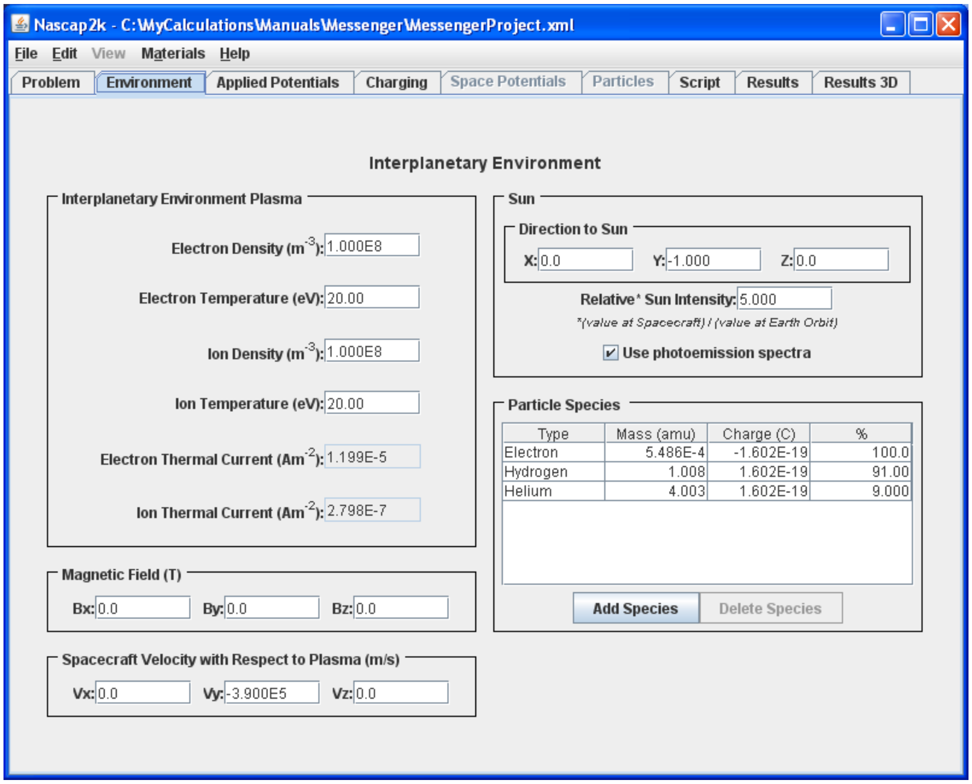
Figure 14. The Environment Tab for Studies in an Auroral Environment

Table 9. Input Parameters for the Auroral Environment Tab

AURORAL ENVIRONMENT	
PARAMETER	**DEFINITION**
Auroral Environment Plasma	
Low Energy	
Density	Number density of the low energy (< 5eV) plasma (m^{-3}).
Temperature	Temperature of the low energy (< 5eV) plasma (eV).
Debye Length	Debye length of the ambient plasma (m).
Electron Current	Electron thermal current (Am^{-2}).
Ion Current	Ion thermal current (Am^{-2}).
Maxwellian	Contribution to high energy auroral electron spectrum described by a Maxwellian.
Electron Current	Current of Maxwellian component of flux (Am^{-2}).
Temperature	θ_{max} in equation above (eV).
Density	Partial number density due to Maxwellian component of flux (m^{-3}).
Coefficient	ζ_{max} in equation above.
Gaussian	Contribution to high energy auroral electron spectrum described by a Gaussian.
Electron Current	Current of Gaussian component of flux (Am^{-2}).
Energy	E_{gauss} in equation above (eV).
Width	Δ in equation above (eV).
Density	Partial number density due to Gaussian component of flux (m^{-3}).
Coefficient	ζ_{gauss} in equation above.
Power Law	Contribution to high-energy auroral electron spectrum described by a Power Law.
Electron Current	Current of Power Law component of flux (Am^{-2}).
1st Energy	Minimum energy at which the Power Law portion of the flux equation contributes (eV).
2nd Energy	Maximum energy at which the Power Law portion of the flux equation contributes (eV).
Exponent	α in equation above.
Density	Partial number density due to Power Law component of flux (m^{-3}).
Coefficient	ζ_{power} in equation above.
Magnetic Field	
Bx, By, Bz	Components of the ambient magnetic field vector (tesla) in the spacecraft frame of reference.
Spacecraft Velocity	
Vx, Vy, Vz	Components of the spacecraft velocity vector (m/s). (Used for computing ram ion and wake effects.)
Sun	
Sun Direction (X,Y,Z)	Direction toward the sun in the spacecraft frame of reference.
Relative Sun Intensity	Ratio of sun intensity at the spacecraft over the 1 AU value.
Particle Species	Specification of particle species through their mass, charge, and percentage of the total plasma density.

11.4 Interplanetary Environment

The tab for definition of an interplanetary environment is shown in Figure 15. The plasma is taken to be a streaming Maxwellian. The density and temperature for the electrons and ions are defined. The ions species are specified in the table. The solar wind streaming velocity is the negative of the spacecraft velocity with respect to the plasma. By default, the ion current to surface elements facing in the velocity direction that are shadowed by other surface elements is zero. This behavior can be changed by changing the shadowIons attribute within the **Environments** folder of the **Charge Surfaces** command in the script (See Section 16.2 and Table 21). Table 10 summarizes the parameters of the **Interplanetary Environment** tab.



Interplanetary Environment

Interplanetary Environment Plasma

Electron Density (m^{-3}): 1.000E8

Electron Temperature (eV): 20.00

Ion Density (m^{-3}): 1.000E8

Ion Temperature (eV): 20.00

Electron Thermal Current (Am^{-2}): 1.199E-5

Ion Thermal Current (Am^{-2}): 2.798E-7

Magnetic Field (T)

Bx: 0.0 By: 0.0 Bz: 0.0

Spacecraft Velocity with Respect to Plasma (m/s)

Vx: 0.0 Vy: -3.900E5 Vz: 0.0

Sun

Direction to Sun

X: 0.0 Y: -1.000 Z: 0.0

Relative* Sun Intensity: 5.000

*(value at Spacecraft) / (value at Earth Orbit)

☑ Use photoemission spectra

Particle Species

Type	Mass (amu)	Charge (C)	%
Electron	5.486E-4	-1.602E-19	100.0
Hydrogen	1.008	1.602E-19	91.00
Helium	4.003	1.602E-19	9.000

Figure 15. The Environment Tab for Studies in Interplanetary Space

Table 10. Input Parameters for the Interplanetary Environment Tab

INTERPLANETARY ENVIRONMENT	
PARAMETER	**DEFINITION**
Interplanetary Environment Plasma	
Electron Density	Number density of the ambient electrons (m^{-3}).
Electron Temperature	Temperature of the ambient electrons (eV).
Ion Density	Number density of the ambient ions (m^{-3}).
Ion Temperature	Temperature of the ambient ions (eV).
Electron Thermal Current	Electron thermal current (Am^{-2}).
Ion Thermal Current	Ion thermal current (Am^{-2}).
Magnetic Field	
Bx, By, Bz	Components of the ambient magnetic field vector (tesla) in the spacecraft frame of reference.
Spacecraft Velocity	
Vx, Vy, Vz	Components of the spacecraft velocity vector (m/s). (Used for computing ram ion and wake effects.)
Sun	
Direction to Sun (X,Y, Z)	Direction toward the sun in the spacecraft frame of reference.
Relative Sun Intensity	Ratio of sun intensity at the spacecraft over the 1 AU value.
Use photoemission spectra	See Section 11.5. (Enabled only if at least one material has a photoemission spectrum defined.)
Particle Species	Specification of particle species through their mass, charge, and percentage of the total plasma density.

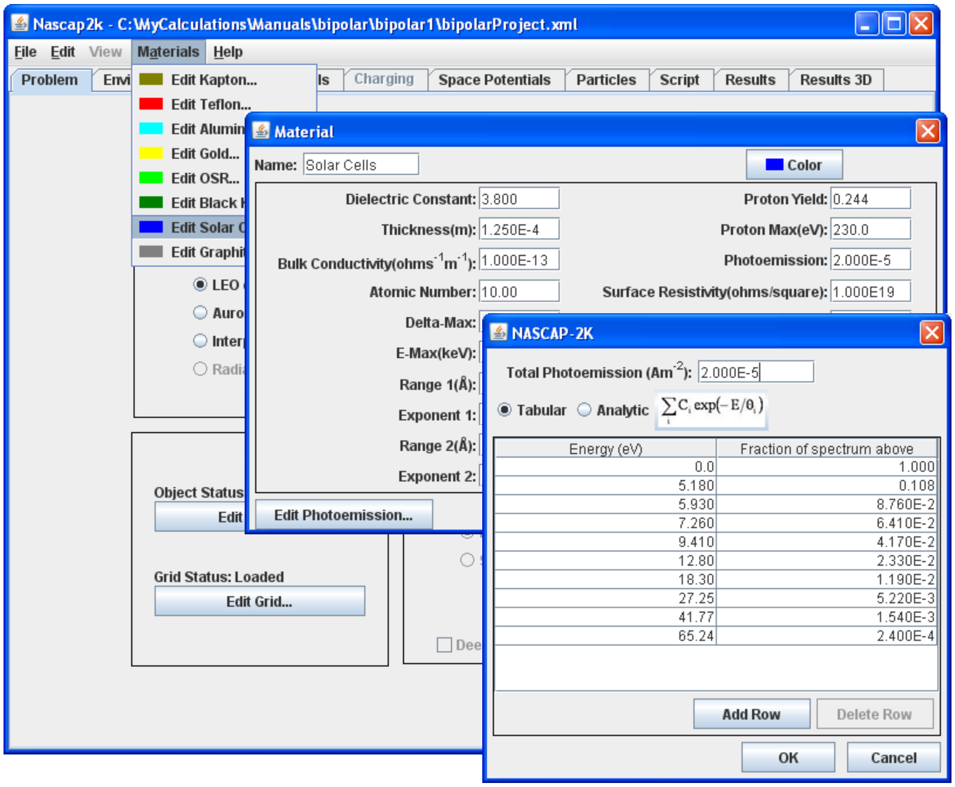
11.5 Using Photoemission Spectra

Spacecraft in the solar wind or in a very tenuous plasma normally charge to positive potentials (a few volts to tens of volts) to balance the emitted photoelectron current with a very low current of ambient electrons. Determining just how positive a spacecraft charges requires knowledge of the high-energy portion of the photoemission spectrum. (This is not required for geosynchronous charging, in which surfaces never achieve positive potentials of more than a few volts.)

Clicking the “Edit Photoemission…” button on the **Material** definition dialog box brings up the **Photoemission Spectrum** dialog box. The **Material** definition dialog box is discussed in Section 13.4. *For Nascap-2k to realize that the explicit photoemission spectrum should be used, the user must at least view the default spectrum, even if she/he does not want to change it.*

A *Nascap-2k* tabular definition of a photoemission spectrum consists of the total emission and a sequence of energy-value pairs, where the value indicates the fraction of the photoemission spectrum lying above the energy. As an example, Figure 16 shows a single spectrum based on data from the WIND spacecraft. Alternatively, the spectrum may be specified by an analytic formula, which gives the photocurrent above an energy as a sum of thermal components. The spectrum is scaled to give the specified total photoemission. The default analytic spectrum, taken from the paper of Nakagawa et al.[12], is $J = 53e^{-E/1.6} + 21e^{-E/3} + 4e^{-E/8.9}$.

The spectrum for each material must be set separately. In addition, for the **Charge Surfaces** module to use the specified photoemission spectrum, the script must include the second-level command “ReadPhotoemission.” If no spectrum is specified, the photoemission spectrum is assumed to be a 2 eV Maxwellian. However, note that tenuous plasma calculations that use a 2 eV Maxwellian for the photoemission spectrum fail to predict the charging to tens of volts of positive potential that is commonly observed.



Name: Solar Cells

Dielectric Constant: 3.800

Thickness(m): 1.250E-4

Bulk Conductivity(ohms^{-1}m^{-1}): 1.000E-13

Atomic Number: 10.00

Delta-Max:

E-Max(keV):

Range 1(Å):

Exponent 1:

Range 2(Å):

Exponent 2:

Proton Yield: 0.244

Proton Max(eV): 230.0

Photoemission: 2.000E-5

Surface Resistivity(ohms/square): 1.000E19

Total Photoemission (Am^{-2}): 2.000E-5

● Tabular ○ Analytic $\sum_i C_i \exp(-E/\theta_i)$

Energy (eV)	Fraction of spectrum above
0.0	1.000
5.180	0.108
5.930	8.760E-2
7.260	6.410E-2
9.410	4.170E-2
12.80	2.330E-2
18.30	1.190E-2
27.25	5.220E-3
41.77	1.540E-3
65.24	2.400E-4

Figure 16. Photoemission Spectrum Dialog Box

Both close (~0.1 AU) to the sun where photoemission is high and on a very large spacecraft (e.g., Solar Sail) for which divergence is low, the density of photoemitted electrons can be so high that they form a space charge barrier to their escape. The barrier reduces the net photocurrent and lowers the surface potential. This problem was studied analytically by Guernsey and Fu,[13] and, more recently, numerically by Ergun *et al*.[14] When the second level script command “SetParameters” with the argument “SpaceChargeLimitedPhotoemission” set to “On” is included in the script, a preliminary *Nascap-2k* model is used to compute the barrier height and reduce the net photocurrent and the secondary electron current. The model depends on the plasma density, the photoemission current, the spacecraft shape, and an assumed shape of the photoemission spectrum. Additional details are in *Nascap-2k Scientific Documentation*.

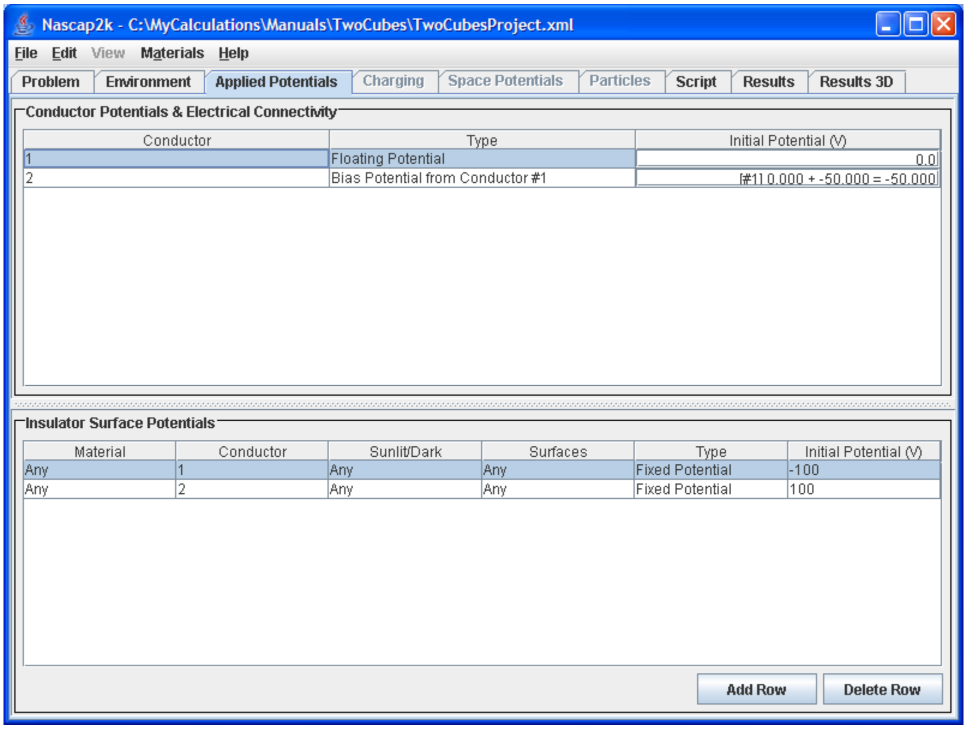
12 Specifying Potentials on Surfaces (Applied Potentials Tab)

Figure 17 shows the **Applied Potentials** tab for a two-conductor problem. This tab is used to specify applied and initial potentials on conductors and insulating surface elements. The top portion is used to specify if each conductor is (1) held at a fixed potential, (2) allowed to float, or (3) held at a fixed bias with respect to chassis ground (conductor 1). (A time-varying bias potential can be specified directly in the script. See Section 16.2.) Potentials on conducting elements are assigned by specifying the value of the potential in the last column ("Initial Potential"). In Figure 17, the potential of conductor 1 is specified to be floating with respect to the environment with an initial value of 0 V, and conductor 2 is biased by -50 V from conductor 1. Insulating surface elements not specified on the bottom portion of this tab are assigned the initial potentials of their underlying conductor.

The lower portion of this tab is used to specify the initial potential on insulating surface elements. Elements are selected by material name, conductor number, and sunlit or dark condition.

NOTE: *When a material is changed from a conductor to an insulator or from an insulator to a conductor,* Nascap-2k *should be closed and restarted in order to update the materials available in this portion of the tab.*

Individual elements may also be specified by number. Presently, only fixed potential boundary conditions can be specified. In Figure 17, the potential of all the insulating elements of conductor 1 are specified to be initialized to -100 V, and the potential of all the insulating elements of conductor 2 are specified to be initialized to +100 V. Table 11 summarizes the options on the **Applied Potentials** tab.



Conductor Potentials & Electrical Connectivity

Conductor	Type	Initial Potential (V)
1	Floating Potential	0.0
2	Bias Potential from Conductor #1	[#1] 0.000 + -50.000 = -50.000

Insulator Surface Potentials

Material	Conductor	Sunlit/Dark	Surfaces	Type	Initial Potential (V)
Any	1	Any	Any	Fixed Potential	-100
Any	2	Any	Any	Fixed Potential	100

Figure 17. Potential Initialization for Objects in a Two-Conductor Problem

Table 11. Input Parameters for the Applied Potentials Tab

APPLIED POTENTIALS	
PARAMETER	**DEFINITION**
Conductor Potentials & Electrical Connectivity	
Conductor	Specified by a numerical identifier (1, 2, etc.) during the definition of the object.
Type	Specifies the potential boundary condition on the conductor. Available options are Floating Potential, Fixed Potential (conductor 1 only), and Bias Potential (relative to conductor 1).
Initial Potential	Specifies the initial value of the conductor potential (V). Double-click field to edit.
Insulating Surface Potentials	
Material	Select surface elements of specified material.
Conductor	Select surface elements of specified underlying conductor.
Sunlit/Dark	Select surface elements by orientation with respect to the sun (facing toward or away).
Surfaces	Select specific surface element by number.
Type	Specifies the potential boundary condition on the specified surface elements. Fixed Potential is the only option at present.
Initial Potential	Specifies the initial value of the insulator potential (V).

13 Surface Charging (Charging Tab)

13.1 Background

Spacecraft surface charging is the accumulation of charge on spacecraft surfaces. As illustrated in Figure 18, several different current components can contribute to the charging.[9,15,16, 17] The high-energy incident electrons of the geosynchronous and auroral environments generate secondary electrons and backscattered electrons from surfaces. High-energy incident ions also generate secondary electrons. The current density of low-energy electrons generated by solar ultraviolet radiation normally exceeds that of the net plasma current in geosynchronous orbit and in interplanetary space. While, in low-Earth orbit (equatorial and polar), the incident low-energy particles dominate the current.

Charging simulations are complicated by the fact that the rest of the spacecraft influences the potential of each surface. In order to compute surface potentials, spacecraft geometry, surface materials, and environment must all be considered. Each insulating spacecraft surface interacts separately with the plasma and is capacitively and resistively coupled to the frame and other surfaces. *Nascap-2k* uses this information to compute the time history of the surface potentials and fluxes.

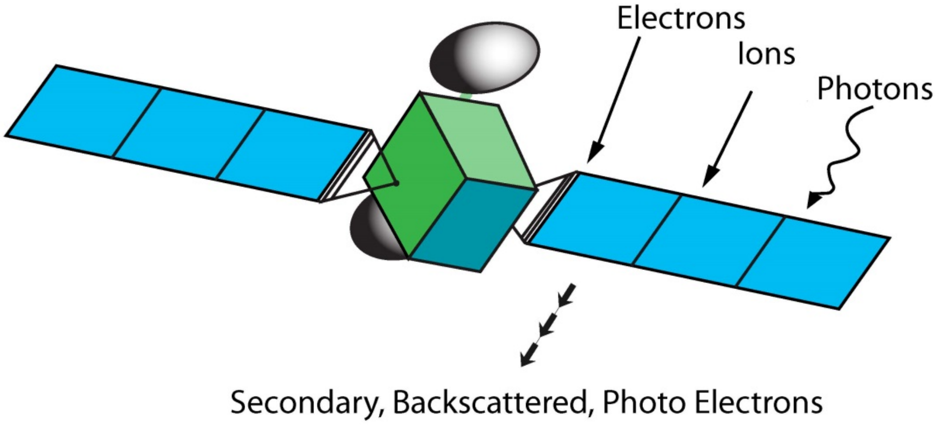


Figure 18. High Negative Potentials Can Result from the Accumulation of Charge on Spacecraft Surfaces

Figure 19 shows a circuit diagram for a spacecraft with one insulating surface element and exposed conducting surfaces. The widely differing capacitances of the surface to infinity, C_A, and of the surface to spacecraft ground, C_{AS}, make this a complex numeric problem.

$$C_{AS} = \kappa \varepsilon_0 \frac{S}{d} \approx \frac{S}{2} \times 10^{-7} \quad \text{Farad} \qquad (5)$$

$$C_A \approx C_S \approx 4\pi\varepsilon_0 r \approx r \times 10^{-10} \text{ Farad} \qquad (6)$$

where κ, d, and S are the dielectric constant, thickness, and surface area of the insulating surface element, r is the radius of an equivalent sphere, and ε_o is the permittivity of vacuum. The potentials as a function of time are computed using implicit time integration of the charging equations, which relate the derivative of the potential, **Φ**, with time to the current, **I**.

$$\begin{aligned} \mathbf{C}_A \dot{\mathbf{\Phi}}_A + \mathbf{C}_{AS}\left(\dot{\mathbf{\Phi}}_A - \dot{\mathbf{\Phi}}_S\right) &= \mathbf{I}_A \\ -\mathbf{C}_{AS}\left(\dot{\mathbf{\Phi}}_A - \dot{\mathbf{\Phi}}_S\right) + \mathbf{C}_A \dot{\mathbf{\Phi}}_S &= \mathbf{I}_S \end{aligned} \qquad (7)$$

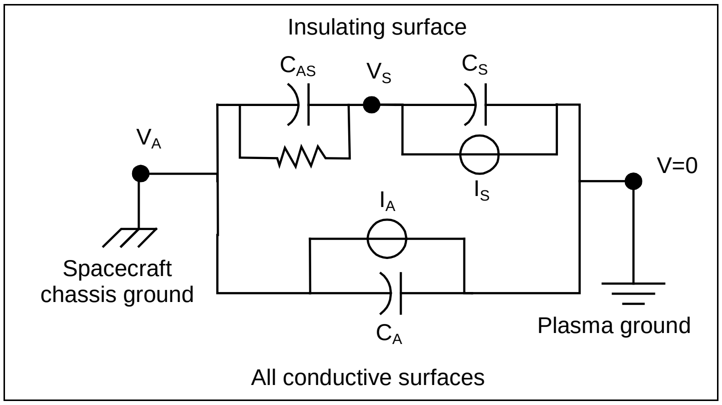


Figure 19. Circuit Model of a Spacecraft with One Insulating Surface Element

The multisurface problem is solved by linearizing the currents and inverting the matrix.

$$\mathbf{C}\dot{\mathbf{\Phi}} = \mathbf{I}(\mathbf{\Phi}) \tag{8}$$

13.2 Numerical Approach and Implementation in *Nascap-2k*

Among the difficulties of developing accurate and robust algorithms for spacecraft charging has been the inability to calculate accurate electric fields, let alone predict how electric fields change as a result of surface potential changes. *Nascap-2k* uses the Boundary Element Method[7] to calculate accurate electric fields and as the basis for implicit charging equations.

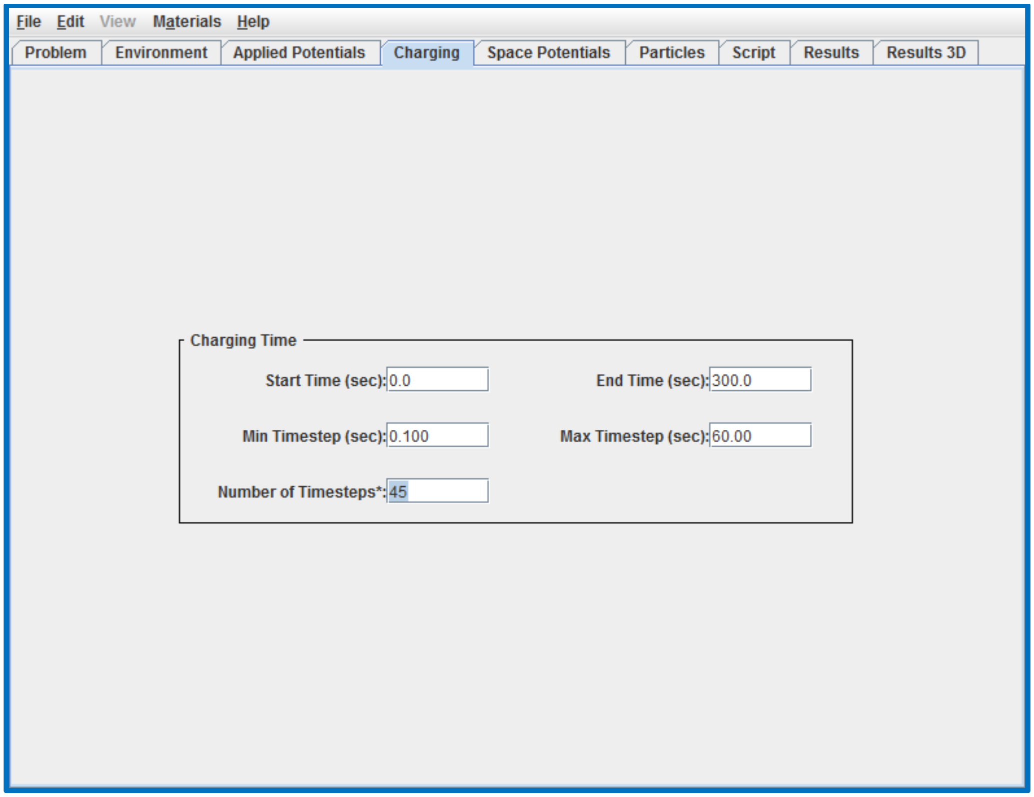
The Boundary Element Method is a means for relating fields and potentials in a region to sources on the region's boundary. It is comparable to a sum over the coulomb fields of all the charges in a region rather than an iterative field solution. In our case, the region is the space exterior to a spacecraft and the boundary is the spacecraft surface. Also, we assume the "free space Green's function." i.e.*,* the potentials in the region obey Laplace's equation.

The **Charging** tab shown in Figure 20 is used to specify the time-stepping parameters used in calculations of surface charging. The parameters are summarized in Table 12. If the **Results** tab display indicates that potentials are unphysically bouncing up and down from one timestep to the next, taking more (shorter) timesteps may reduce or eliminate the problem. The "Start Time" and "End Time" allow specification of a sequence of changing environments for specified time intervals.

A reasonable timestep is $\tau = \frac{j}{c}\Delta\phi$, where j is the maximum surface current density, c is the appropriate capacitance per unit area, and $\Delta\phi$ is an approximate change in potential during the timestep. The appropriate capacitance is either the capacitance to space for overall charging or the capacitance to the underlying conductor for differential charging. In denser plasmas, the timesteps should be set *much* shorter than the default values. As the Boundary Element Method, used to determine the system capacitance, assumes no plasma, the calculated chassis charging rate in dense plasmas is generally unrealistically fast. However, the steady-state solution, which is determined by current balance, and the differential charging rates, determined by surface-to-chassis capacitance, is correct.

Script options (see Section 16) are used to specify whether the environment currents are given by analytic expressions or by the most recent tracked particle currents. When the environment currents are specified analytically, the values are given by the orbit-limited current from the specified environment, which is usually correct for the repelled species but not for the attracted species, especially in dense plasma. The LEO and Solar Wind plasmas are taken to be flowing Maxwellians. The low energy component of the auroral plasma is also taken to be a flowing Maxwellian. For dense plasma with a Debye length short compared with the system size, this assumption may significantly overestimate the environment current. In a long Debye length plasma, this assumption overestimates the environment current to cavities and other shielded regions.

The environment specified in the script is used to determine the secondary and backscattered yields even if the environment currents are computed by particle tracking.



Start Time (sec): 0.0

End Time (sec): 300.0

Min Timestep (sec): 0.100

Max Timestep (sec): 60.00

Number of Timesteps*: 45

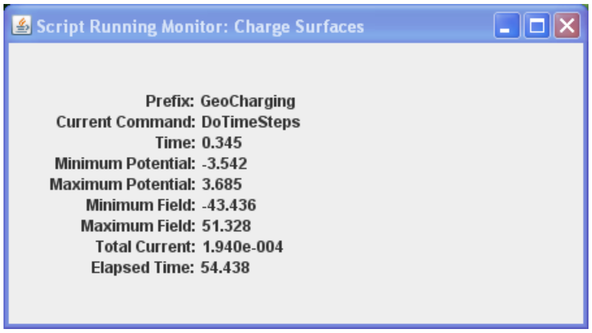
Figure 20. Charging Tab: Specifying Parameters for Spacecraft Charging Calculations

Table 12. Input Parameters for the Charging Tab

CHARGING	
PARAMETER	**DEFINITION**
Start Time	Time (sec) to start charging calculation (usually zero).
End Time	Time (sec) to end charging calculation (usually real-time duration).
Min Timestep	Shortest (first) timestep (sec) during charging calculation.
Max Timestep	Longest (final) timestep (sec) during charging calculation.
Number of Timesteps	Total number of timesteps used during the charging calculation. Same quantity as “Number of Iterations” on the Space Potentials tab.

13.3 Monitoring the Calculation

When a charging calculation is launched, the **Script Running Monitor** indicates the progress of the calculation. The monitor shown in Figure 21 is for a sample charging calculation of a spacecraft in a geosynchronous-type environment. The monitor displays, among other information, the simulated time, the clock time, and the minimum and maximum spacecraft potentials at the present timestep.

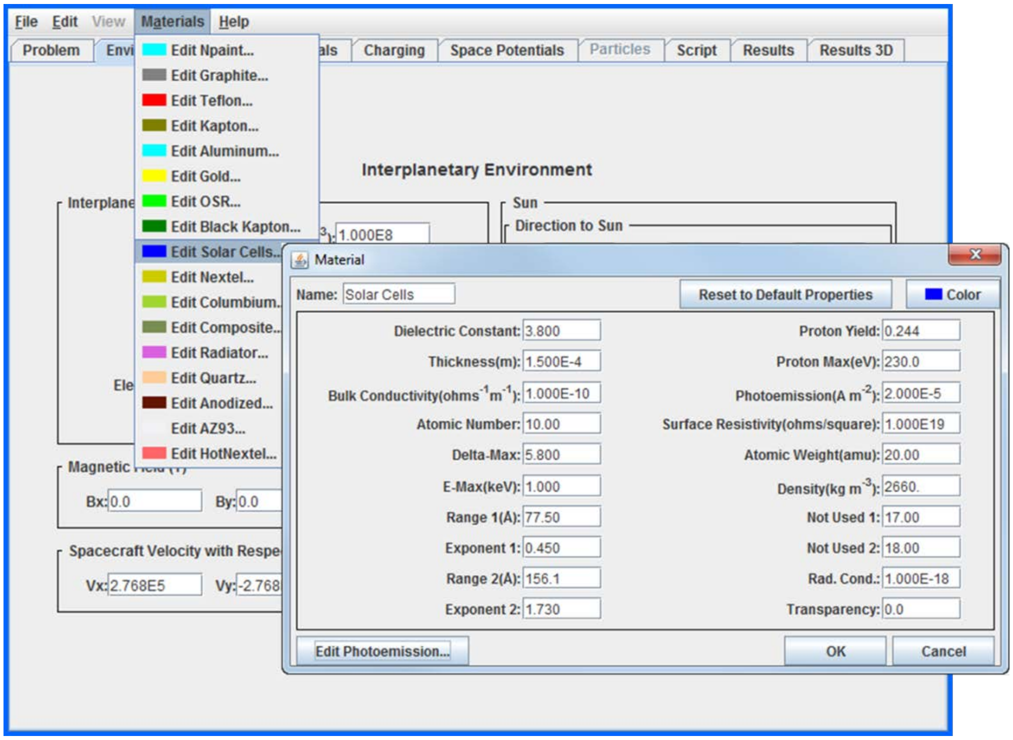


Prefix: GeoCharging
Current Command: DoTimeSteps
Time: 0.345
Minimum Potential: -3.542
Maximum Potential: 3.685
Minimum Field: -43.436
Maximum Field: 51.328
Total Current: 1.940e-004
Elapsed Time: 54.438

Figure 21. Script Running Monitor Showing Charging Calculation

13.4 Materials

A material name is associated with each surface element of the *Nascap-2k* object. Each material name is in turn associated with a set of material properties than can be edited, either in *Object Toolkit* or *Nascap-2k*, using the **Materials** menu. *Nascap-2k* uses these properties to determine if each element is an insulator or a conductor and then to compute each of the components of the net current to each element and through each element to the underlying conductor. The **Material** dialog box is shown in Figure 22. The “Reset to Default Properties” button restores material property values to their default values for the displayed material.



3): 1.000E8

Bx: 0.0 By: 0.0

Vx: 2.768E5 Vy: -2.768

Name: Solar Cells

Dielectric Constant: 3.800
Thickness(m): 1.500E-4
Bulk Conductivity(ohms^{-1}m^{-1}): 1.000E-10
Atomic Number: 10.00
Delta-Max: 5.800
E-Max(keV): 1.000
Range 1(A): 77.50
Exponent 1: 0.450
Range 2(A): 156.1
Exponent 2: 1.730

Proton Yield: 0.244
Proton Max(eV): 230.0
Photoemission(A m^{-2}): 2.000E-5
Surface Resistivity(ohms/square): 1.000E19
Atomic Weight(amu): 20.00
Density(kg m^{-3}): 2660.
Not Used 1: 17.00
Not Used 2: 18.00
Rad. Cond.: 1.000E-18
Transparency: 0.0

Figure 22. *Nascap-2k* Materials Menu Showing Material Property Editing Dialog Box

The “Import Materials from SEE Handbook” option on the **File** menu allows users to import material property files in the format created by the *SEE Interactive Spacecraft Charging Handbook*. We recommend the *SEE Handbook* as an aid to the determination and preliminary assessment of material property sets. To use material definitions from the *SEE Handbook* in

Nascap-2k, first define the materials in the Handbook. Save the Handbook parameters by clicking the "Save" button along the top and note where the file is saved. In *Nascap-2k,* select "Import SEE Handbook Materials File…" on the **File** menu and browse to the saved file.

A folder of material properties measured by Utah State University in this format is placed in the installation folder (**Nascap2k_4/Materials**) during the *Nascap-2k* installation.

The meaning and use of each of the material properties are listed in this section. Additional details of the yield models are in *Nascap-2k Scientific Documentation*.

Dielectric constant. This property is the relative dielectric constant for an insulating material

$$\kappa=\frac{\varepsilon}{\varepsilon_o} \tag{9}$$

where ε is the absolute dielectric constant and ε_o is the dielectric constant of free space. κ is dimensionless. It is ignored for conductors.

Thickness. This property is the thickness of a dielectric film covering an underlying conductor in meters. It is ignored for conductors.

Bulk conductivity. This property is the bulk conductivity of the surface material in ohms^{-1} m^{-1}. A negative value indicates that the material is a conductor. If the bulk conductivity is in excess of $10^{-4}\ \Omega^{-1}\ m^{-1}$, the material should be defined as a conductor (value of -1). NOTE: *When a material is changed from a conductor to an insulator or from an insulator to a conductor,* Nascap-2k *should be closed and restarted.*

Atomic number. This property is the atomic number for pure elements or the mean atomic number for chemical compounds; e.g., polyethylene $(CH_2)_n$ has a mean atomic number of (6 + 1 + 1)/3 = 2.7. This value is used to compute the electron backscatter yield.

Secondary yield ("Delta-Max" and "E-Max"). These properties give the size and location of the maximum in the secondary electron yield curve. The secondary yield is the current of secondary electrons emitted over the incident electron current. The secondary yield curve is a plot of secondary yield for normally incident electrons, against the incident energy of the primary electron E. This is shown in Figure 23. δ_{max} is unitless and E_{max} is in keV.

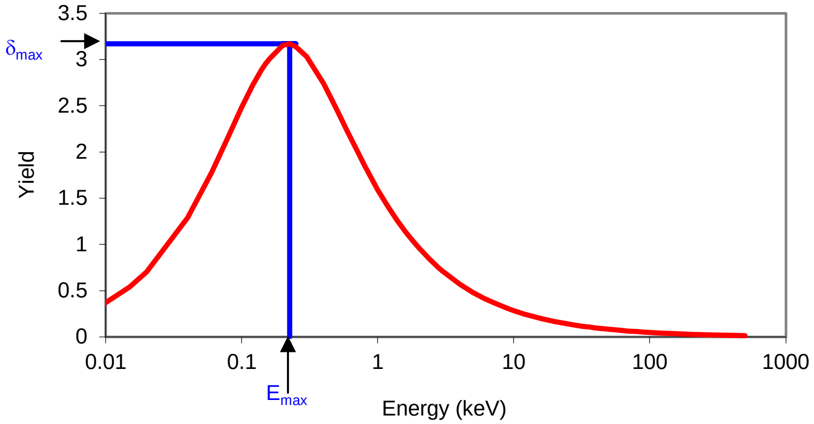


Figure 23. Electron Secondary Yield as a Function of Incident Energy

Electron range ("Range 1," "Exponent 1," "Range 2," "Exponent 2"). Part of the secondary electron emission formulation requires an analytical form for the "range" of electrons in the material. The range is the depth to which the electrons can penetrate the material as they are continuously slowed down by losing energy to the material lattice. *Nascap-2k* uses a bi-exponential form. If b_1, q_1, b_2, and q_2 are the four properties, the range R is given by

$$R = b_1 E^{q_1} + b_2 E^{q_2} \qquad (10)$$

where the bs are the "Range" parameters and the qs are the "Exponents." The four parameters are obtained from fits to stopping power data. The range is determined in angstroms. If no reliable stopping power data or four parameter fits are available, the range may be estimated from Feldman's formula[18] automatically by assigning -1 to Range 1. In this mode these properties are assigned as follows:

Range 1	=	-1
Exponent 1	=	null
Range 2	=	material density (g cm^3)
Exponent 2	=	mean atomic weight (AMU)

Ion-induced secondary emission ("Proton Yield" and "Proton Max"). Secondary emission of electrons due to ion impact is treated using a two-parameter fit. "Proton Yield" is the yield for 1 keV normally incident protons and "Proton Max" is the proton energy in keV that produces the maximum electron yield. The secondary emission properties due to the impact of ions other than protons are assumed to be identical to the proton values for the same energy.

Photoemission. This property contains the yield of photoelectrons from the surface material exposed to a normally incident solar spectrum in amperes per square meter.

Surface resistivity. This property gives the intrinsic surface resistivity in "ohms per square." This rather odd unit is used to distinguish the resistivity coefficient from the actual surface resistance (in ohms). Consider two points in a plane A and B, a distance L_1 apart. If L_2 is the "width" of the plane surface resistance = surface resistivity × $\frac{L_1}{L_2}$

i.e., ohms = (ohms per square) x dimensionless geometrical factor

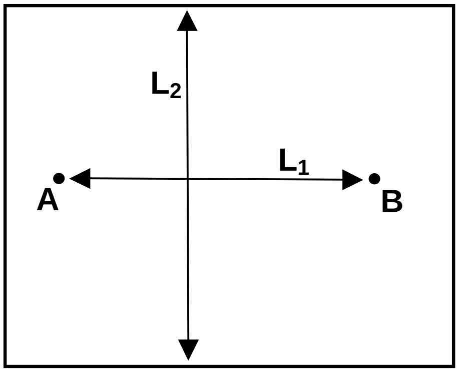


Figure 24. Illustration of Surface Resistivity

Nascap-2k uses the surface resistivity per square times and the surface geometry to determine the surface resistance between two adjacent surface elements or between a surface and a grounding element. The intrinsic surface conductivity is due to the migration of electrons along the surface layer, possibly aided by adsorbed impurities and defects. A negative value indicates that the material is a conductor.

Transparency. This property is used to model current collection of transparent surfaces, such as wire meshes. The fraction of the incident current (analytic and tracked) collected by each surface element is (1-t), where t is the transparency. Caution should be exercised when using non-zero values with tracked currents, as all particles are stopped by the surface element—leaving some of the current unaccounted for.

Other properties. The “Atomic Weight,” “Density,” and “Rad. Cond” values are not used at present by *Nascap-2k*.

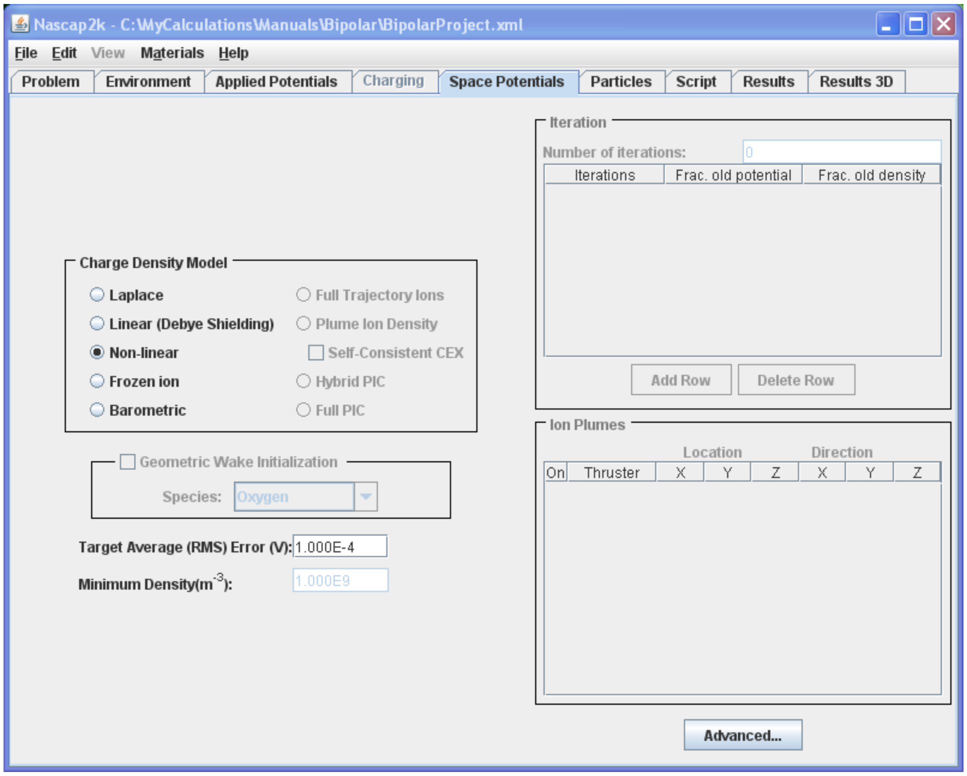
13.5 Surface Conductivity

Nascap-2k can include surface conductivity in charging calculations. Surface conductivity operates between insulating surface elements of a common material and with a common edge, thus covering transport over a wide expanse of such material. The material can be grounded by a strip at a surface element edge or by a circular contact located at a node. Grounding edges and nodes are specified within *Object Toolkit* by selecting the “Conductivity” option on the **Mesh** menu. Grounding elements can be specified only for primitive components, because other types of components frequently have their meshes re-created. A grounding edge establishes conductance to ground from each of the two neighboring elements of $L/D\kappa$, where L is the length of the edge, D is the distance from the center of the surface element to the center of the edge, and κ is the surface resistivity of the material. A grounding node establishes conductance to ground from each of the neighboring elements of $\frac{\Omega}{\left(\ln\left(D/r\right)\kappa\right)}$, where Ω is the angle the element subtends at the node, D is the distance from the element center to the node, and r is the user-specified node radius.

14 Calculating Electric Potentials in Space (Space Potentials Tab)

To compute space potentials, the user checks “Potentials in Space or Detector Analysis” on the **Problem** tab. There are many reasons why calculation of the potential structure in the surrounding space might be desired, including the generation of sheath currents and the study of charged particle trajectories.

A number of space charge formulations are available in *Nascap-2k* for solving Poisson’s equation, $-\nabla^2\phi = \rho/\varepsilon_o$, for the electrostatic potential about the object. Space charge may be computed either fully by particles, fully analytically, or in a hybrid manner, and with flexible boundary conditions on the object and at the grid boundary. Figure 25 shows the **Space Potentials** tab, which is used to select a charge density model and specify parameters for the potential solution. The available charge density models are described in Section 14.1. The input parameters that appear on the **Space Potentials** tab are listed in Table 13.



Number of iterations: 0

Charge Density Model

○ Laplace
○ Linear (Debye Shielding)
● Non-linear
○ Frozen ion
○ Barometric
○ Full Trajectory Ions
○ Plume Ion Density
□ Self-Consistent CEX
○ Hybrid PIC
○ Full PIC

□ Geometric Wake Initialization

Species: Oxygen

Target Average (RMS) Error (V): 1.000E-4

Minimum Density(m^{-3}): 1.000E9

Figure 25. Space Potentials Tab, Used to Specify Options and Parameters for Calculation of Potentials in Space

Table 13. Input Parameters for the Space Potentials Tab

SPACE POTENTIALS	
PARAMETER	**DEFINITION**
Charge Density Model	The charge density models that are available depend on “Problem Type” parameters selected on the **Problem** tab.
Laplace	Zero space charge.
Linear (Debye Shielding)	Linear (Debye) shielding.
Non-linear	Standard equilibrium space-charge formula for high-density plasmas.
Frozen ion	Ion density equal to the ambient plasma density everywhere. Electron density is $n \times \exp(\phi/\theta)$ for negative potentials, and $n(1+\phi/\theta)$ for positive potentials.
Barometric	Ion density equal to the plasma density decreased by the wake factor. Electron density is $n \exp(\phi/\theta)$ for negative potentials, and $n \times (1+\phi/\theta)$ for positive potentials.
Full Trajectory Ions	Space charge from ion trajectories. Electron density is $n \times \exp(\phi/\theta)$ for negative potentials, and $n \times (1+\phi/\theta)$ for positive potentials. Used to calculate potentials in space self-consistent with ion trajectories. “Non-linear” used for initialization.
Plume Ion Density	Use ion density computed by summing the contributions from the thruster plumes in full trajectory ions expression for charge density. Requires imported plume map.
Hybrid PIC	Ion density from tracking of macroparticles. Electron density is $n \times \exp(\phi/\theta)$ for negative potentials, and $n \times (1+\phi/\theta)$ for positive potentials. Only available for time-dependent plasma calculations. “Non-linear” used for initialization.
Full PIC	Ion and electron densities from particle tracking results. Only available for time-dependent plasma calculations. “Frozen ion” used for initialization.
Geometric Wake Initialization	Compute wake of the (uncharged) object (Neutral Approximation), using the “Spacecraft velocity” (as specified on the **Environment** tab). The calculation is only done in a “New” potential run (iteration 0). (Option is only available in dense plasmas: LEO and auroral.)
Species	Mass of the selected species is used to compute geometric wake. (Mass is defined on the **Environment** tab.)
Target Average (RMS) Error	Root mean square error below which the potential is considered converged.
Minimum Density (m^{-3})	Reference density n_{min} for “Full Trajectory Ion” or “Plume Ion Density” calculation.
Iteration	Relevant only for iterative (“Self-consistent with Ion Trajectories,” “Consistent with Plume Ion Densities,” and “Charging” with “Tracked Particle Currents”) and “Time-dependent” calculations.
Number of iterations	Number of times to iterate using preexisting solution.
Fraction old potential	Fraction of potential solution from previous iteration of the potential solver to use in new iteration.
Fraction old density	Fraction of density solution from previous iteration of the particle tracker to use in new iteration.
Ion Plumes	Relevant only for calculations involving an ion thruster plume.
On	Indicates if thruster plasma is included in potential solution.
Thruster	Name of thruster as defined in *Object Toolkit*.
Location	Location of origin of thruster in meters in coordinate system used by **Results 3D** tab.
Direction	Direction of Z-axis of thruster coordinate system.

14.1 Available Space Charge-Density Models

Additional information on the charge density models can be found in Section 1.4.1 of *Nascap-2k Scientific Documentation*.

Laplace. The Laplacian space charge option specifies that the charge density is zero, i.e., charge exists only on object surfaces and external boundaries, as determined by the boundary conditions. "Space charge" iterations may still be required, however, due to the treatment of surface electric fields.

Linear (Debye Shielding). The Linear space charge option solves the Helmholtz or Debye-Hückel equation:

$$-\nabla^2\phi = \frac{\rho}{\varepsilon_o} = -\frac{\phi}{{\lambda_D}^2} \tag{11}$$

Non-Linear. The Non-linear space charge option is appropriate for most low Earth orbit type plasmas. It accounts for space charge acceleration and convergence in a manner based on spherical collection (Langmuir-Blodgett problem).

Frozen Ion. The frozen ion formulation is intended for short timescale (typically sub-microsecond) problems for which it is a good approximation to assume that ions remain stationary and at ambient density ("ion matrix" approximation), but electrons achieve barometric equilibrium.

Barometric. This algorithm is for cases in which all the surfaces are at potentials comparable to or below the plasma temperature and there is a region of low density, such as a plasma wake. The ion density is given by the plasma density decreased by the wake factor and the electrons are treated as barometric. In a dense, short Debye length plasma, the requirement that the ion and electron densities be nearly equal gives strictly barometric potentials, $\phi = \theta \ln\left(\frac{n_{ion}(x)}{n}\right)$, which are negative in regions of ion depletion. In plasmas with a longer Debye length, the wake potential will be considerably less negative. The barometric formulation is *not* appropriate for problems in dense plasma with well-formed space charge sheaths.

Full Trajectory Ions. Ion densities are calculated from steady-state ion trajectories. Electrons are barometric. This algorithm is typically used for steady-state calculations in which geometric or angular momentum considerations limit the access of ions to portions of the computational space. Minimum density should be set 4 to 6 orders of magnitude less than ambient.

Plume Ion Density. Ion densities are computed from the imported plume map file. Electrons are barometric. After the initial iteration, the ion density is computed by summing the main beam contribution from the thruster plumes and the charge density contribution from tracking particles. Tracked particles are assumed to be charge exchange ions. Additional information is available in Appendix E. Minimum density should be set to the ambient value.

Hybrid PIC. This algorithm is used for timescales (typically sub-millisecond) on which it is practical to treat ion motion, but electrons may be considered in barometric equilibrium. The total charge density is the sum of the tracked ion and barometric electron charge densities.

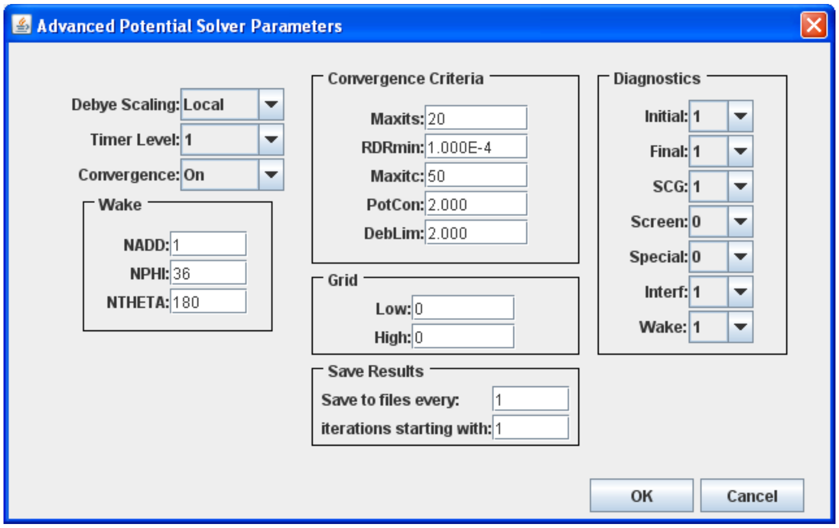
Full PIC. For this option, it is assumed that both the electron and ion-charge densities were obtained by particle tracking.

14.2 Grid Boundary Conditions

For choices of space charge density model in which potentials are substantially screened within the computational space, the nodes on the outermost grid boundary are set to zero. If the space charge density is taken to be zero (the "Laplace" option) the boundary potential is determined by matching an inverse radial falloff outside the grid. If the "Linear" option is chosen, the boundary potential matches a screened inverse radial falloff outside the grid.

14.3 Advanced Potential Solver Parameters

Users have a variety of options to control the potential solver. For most calculations, the default values work well. Figure 26 shows the available parameters on the **Advanced Potential Solver Parameters** dialog box. Table 14 provides descriptions of all the parameters.



Debye Scaling: Local
Timer Level: 1
Convergence: On

NADD: 1
NPHI: 36
NTHETA: 180

Maxits: 20
RDRmin: 1.000E-4
Maxitc: 50
PotCon: 2.000
DebLim: 2.000

Low: 0
High: 0

Save to files every: 1
iterations starting with: 1

Initial: 1
Final: 1
SCG: 1
Screen: 0
Special: 0
Interf: 1
Wake: 1

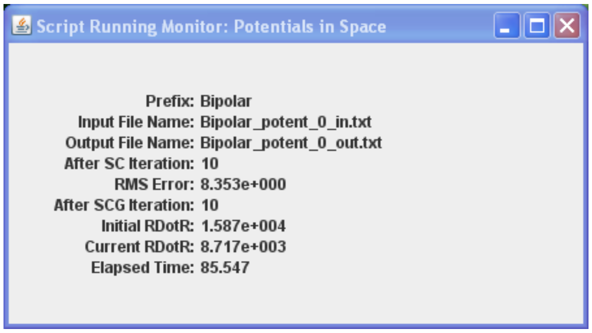
Figure 26. Advanced Potential Solver Parameters Dialog Box

Table 14. Input Parameters for the Advanced Potential Solver Parameters Dialog Box

ADVANCED POTENTIAL SOLVER PARAMETERS	
PARAMETER	**DEFINITION**
Debye Scaling	Specifies if "DebLim" parameter is applied based on the local grid spacing or on the primary grid spacing.
Timer Level	Specifies how often the time since Windows started is output.
Convergence	For the nonlinear space charge formulation, estimate convergence of attracted particle trajectories using local electric field.
Wake	Parameters used to compute geometric wake.
NADD	Number of extra vertices to add to compute object shadow for geometric wake calculation.
NPHI	Number of polar angle divisions in geometric wake calculation.
NTHETA	Number of azimuthal angle divisions in geometric wake calculation.
Convergence Criteria	Normally only the parameters "Maxits" and "RDRmin" are varied from their default values.
Maxits	The maximum number of major or "space charge" potential iterations to be performed.
RDRmin	The value of the "RDotR" parameter below which the potential is considered converged.
Maxitc	The maximum number of minor iterations within each conjugate gradient solution.
PotCon	The number of orders of magnitude that the RDotR parameter drops within each conjugate gradient solution before it is considered converged.
DebLim	The number of Debye screening lengths allowed per volume element. The various space charge formulas limit the amount of space charge in an element in accordance with this parameter.
Grid	It is possible to apply the potential solver to a subset of the *Nascap-2k* grids.
Low/High	Minimum and maximum grid numbers defining the range of grids in which potentials are to be computed. Only useful for special diagnostics calculations.
Save Results	
Save to files every	How often potentials are saved in time-dependent problems,
iterations starting with	starting at this iteration.
Diagnostics	These parameters govern optional diagnostics output from various portions of the potential solver. Level 1 (least) through 5 (most) for each phase of potential calculation.
Initial	Print initial potential values.
Final	Print final potential values.
SCG	Scaled conjugate gradient details.
Screen	Space charge screening details.
Special	Custom routines.
Interf	Grid interface details.
Wake	Geometric wake details.

14.4 Monitoring the Calculation

This section discusses the operation of the potential solver from the point of view of monitoring its progress. In *Nascap-2k* the **Script Running Monitor** displays progress of the calculation of potentials in space, and an output file records the potential solution's progress in detail.



Script Running Monitor: Potentials in Space

```
             Prefix: Bipolar
    Input File Name: Bipolar_potent_0_in.txt
   Output File Name: Bipolar_potent_0_out.txt
  After SC Iteration: 10
          RMS Error: 8.353e+000
 After SCG Iteration: 10
       Initial RDotR: 1.587e+004
       Current RDotR: 8.717e+003
        Elapsed Time: 85.547
```

Figure 27. Script Running Monitor Showing "Potentials in Space" Calculation Progress

A potential solver run consists of an initialization phase, a number of major (space charge) iterations of the potential solution, and a brief exit phase. In the initialization phase, the input parameters are read and echoed, and the database information is processed. Grid information (mesh size and sheath potential) are written to the output file. The grid interface pairs list is formed and written out. Conductor potentials are also written out.

At the beginning of each major potential iteration, the space charge function and its derivative are evaluated volume element by volume element, and the conjugate gradient process is initialized. The "Initial RDotR" is a measure of the current error in the potential solution. For many cases the "Initial RDotR" decreases monotonically beyond the first few major iterations, but lack of such behavior is common and does not indicate an error.

During the conjugate gradient process, the "RDotR" parameter is displayed for each minor iteration. This parameter should generally decrease, but for most cases does not decrease monotonically. The conjugate gradient process is deemed converged when the "PotCon" convergence criterion is satisfied.

The most time-consuming task of the exit phase is to calculate and update surface electric fields. This requires a full matrix operation, as the electric field value is related to the residual for the corresponding potential. The differences between the new and previous potential solutions are expressed as root-mean-square (RMS) errors. If the root-mean-square errors remain constant, solution-mixing may ameliorate or solve the problem. The potential solver concludes when the requested number of major iterations has been performed or when the RMS error has been reduced below its requested value.

15 Calculations Using Particles (Particles Tab)

In *Nascap-2k* macroparticles may be generated and tracked for the purposes that include:

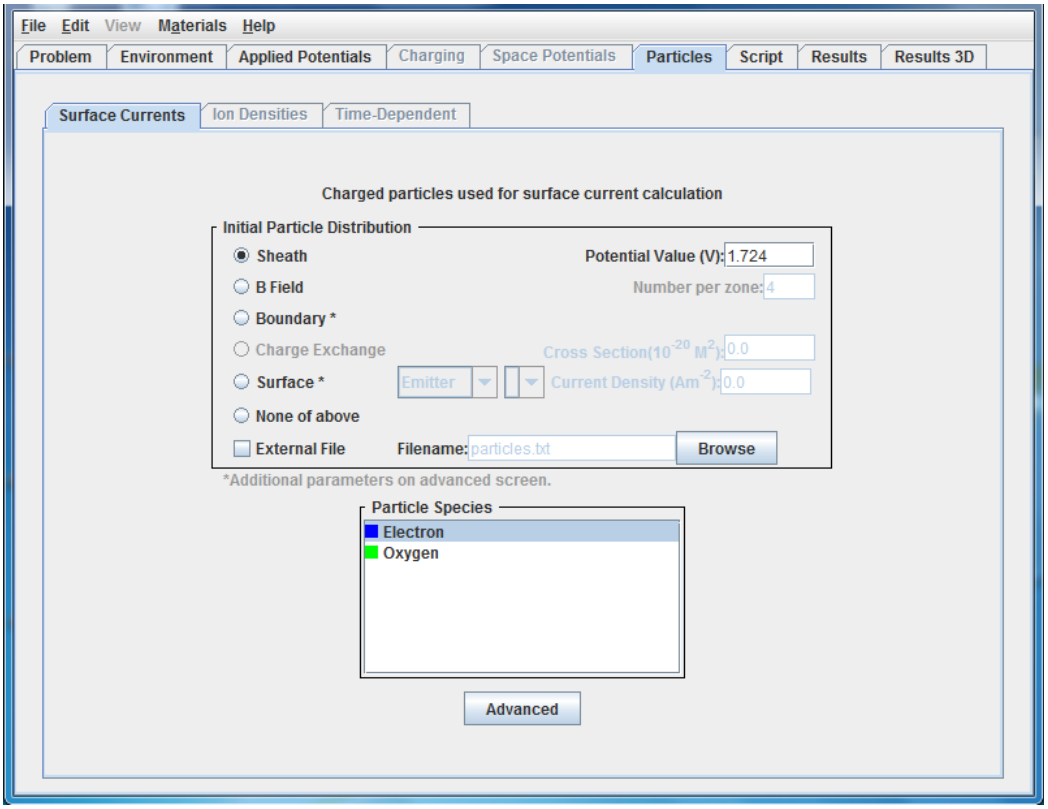
- Studying and/or displaying representative particle trajectories
- Calculating surface currents arising from sheath currents

- Studying wake structure
- Calculating steady-state, self-consistent charge densities
- Calculating time-dependent charge densities and surface currents.

As not every electron or ion can be treated individually, the individual charged particles are collected into macroparticles. Each macroparticle is then treated as a single particle. Henceforth, references to generating and tracking “particles” in *Nascap-2k* refer to macroparticles.

The **Particles** tab is used to specify parameters for the particle generation and tracking. The **Create Particles** module defines the particle species and generates particles as appropriate to the present problem, which may be throughout a volume, along a sheath surface, along a contour line, at problem boundaries, at surface elements, or in accordance with external input. The **Track Particles** module computes the motion of all or a subset of the particles for a maximum time, recording surface currents, accumulating steady-state charge density, or calculating the new charge density at the updated time. After the particle tracker executes, the particle files are left with updated particle positions and velocities, and the time and cycle number is updated in the database. Plotting trajectories is addressed in Section 17.2.

The **Particles** tab has three subtabs (see Figure 28 to Figure 30), which are enabled depending on the choice of “Problem Type” defined on the **Problem** tab. Table 15 summarizes the parameters on the **Particles** tab.



Charged particles used for surface current calculation

Initial Particle Distribution

● Sheath — Potential Value (V): 1.724

○ B Field — Number per zone: 4

○ Boundary *

○ Charge Exchange — Cross Section(10^{-20} M^2): 0.0

○ Surface * — Emitter — Current Density (Am^{-2}): 0.0

○ None of above

□ External File — Filename: particles.txt

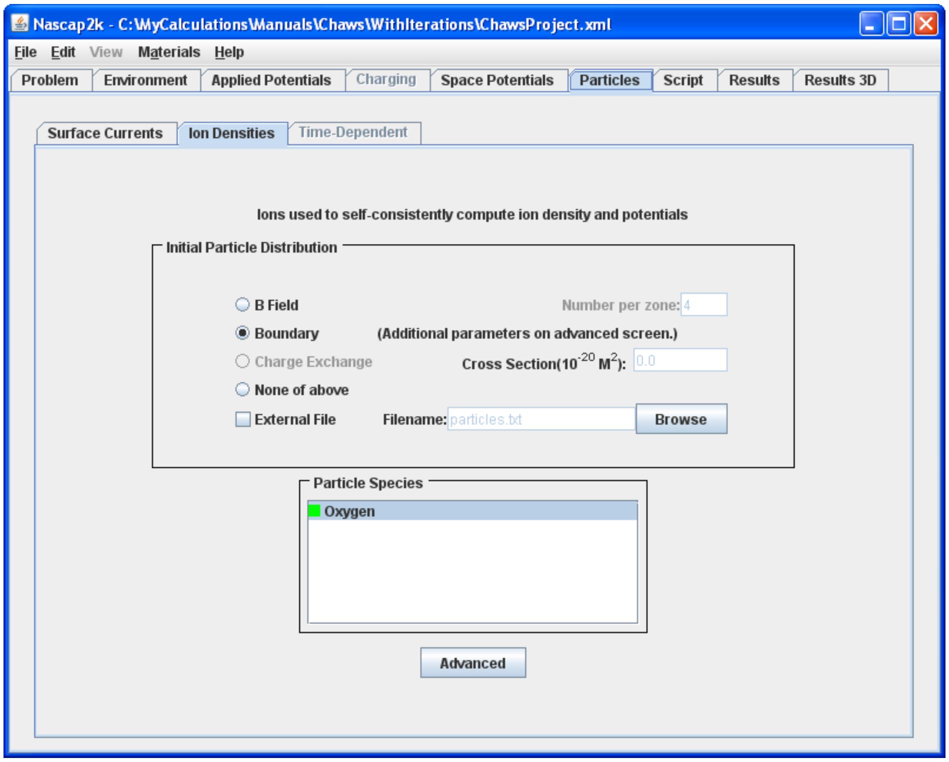
*Additional parameters on advanced screen.

Particle Species

🟦 Electron

🟩 Oxygen

Figure 28. Surface Currents Subtab for Generation and Tracking of Surface Currents



Nascap2k - C:\MyCalculations\Manuals\Chaws\WithIterations\ChawsProject.xml

Ions used to self-consistently compute ion density and potentials

Initial Particle Distribution

○ B Field Number per zone: 4

● Boundary (Additional parameters on advanced screen.)

○ Charge Exchange Cross Section(10^{-20} M^2): 0.0

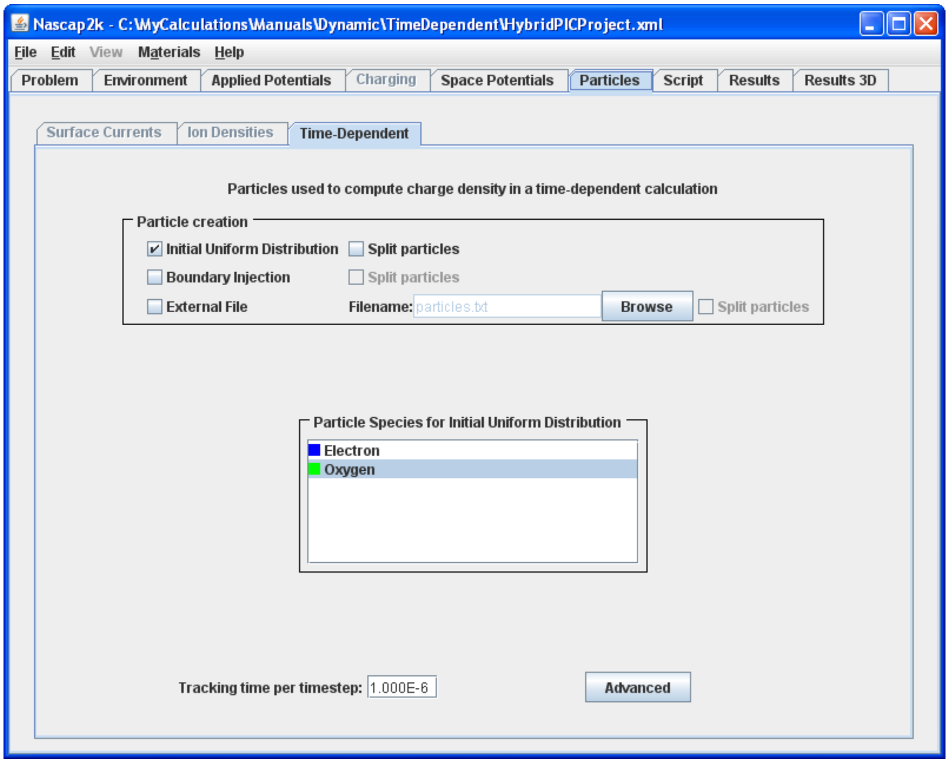
○ None of above

□ External File Filename: particles.txt

Particle Species

🟩 Oxygen

Figure 29. Ion Densities Subtab for Generation and Tracking of Particles for Potentials that are "Self-Consistent with Ion Trajectories"



Nascap2k - C:\MyCalculations\Manuals\Dynamic\TimeDependent\HybridPICProject.xml

Particles used to compute charge density in a time-dependent calculation

Particle creation

☑ Initial Uniform Distribution □ Split particles

□ Boundary Injection □ Split particles

□ External File Filename: particles.txt □ Split particles

Particle Species for Initial Uniform Distribution

🟦 Electron

🟩 Oxygen

Tracking time per timestep: 1.000E-6

Figure 30. Time-Dependent Subtab for Generation and Tracking of Time-Dependent Plasma

15.1 Generating Particles

The choices of initial particle distribution are as follows:

Contour. Generate particles at the intersection of a cut plane and a constant potential surface (such as a sheath). This option is available for visualization only. (See Section 17.2.)

Sheath. Generate particles representing sheath currents at a sheath surface of specified potential. The current density created at a specific sheath section is the plasma thermal current adjusted to account for the ambient magnetic field and the velocity.

Care must be taken when choosing the sheath potential, particularly in cases of high surface potential (compared to temperature) and short Debye lengths (compared to the mesh size). In a highly resolved problem, the appropriate sheath edge potential would be θln2, where θ is the plasma temperature in eV. However, this value must be adjusted at high potentials as *Nascap-2k* limits the rate at which space charge can cause the potential to drop. The **Potentials in Space** module writes the appropriate value to use for each grid to its output file. See Section 17.3.2. The following discussion describes how this value is determined.

The distance in which a specified potential is screened to zero, known as the Child-Langmuir distance, D_{CL}, is expressed in terms of the potential, ϕ, and the Debye length, λ_{Debye}, as follows:

$$D_{CL} = 1.255\left|\phi/\theta\right|^{3/4}\lambda_{Debye} \tag{12}$$

Equating the above equation to the meshing spacing, L, gives

$$\phi_x = 5.1\times10^{-6}L^{4/3}\theta^{1/3}n^{2/3} = 0.74(L/\lambda_{Debye})^{4/3}\theta \tag{13}$$

for plasma density n. The potential ϕ_x may be interpreted as the potential below which *Nascap-2k* underestimates screening. At best, beyond the ϕ_x contour, the potential drops about one order of magnitude per volume element. For θ = 0.1 eV, $n = 10^{11}m^{-3}$, and L = 0.2 m, we find ϕ_x = 6 V. If the 6 V contour is correctly placed, the 0.6 V contour lies at least one element beyond (at the approximate sheath location), and θln2 (0.07 V) is yet another element farther. This would produce a sheath area that is too large. The suggested criterion for the sheath boundary potential is

$$\phi_{SB} = \mathrm{Max}\left(\theta\ln 2, \exp\left(-D_{lim}\right)\phi_x\right) \tag{14}$$

where $\exp(-D_{lim})$ is the planar screening per element allowed by *Nascap-2k*. Note, however, that ϕ_x depends strongly on the grid in which the sheath is found, so that if an increase in object potential moves the sheath from grid 3 to its parent, grid 2, a corresponding larger value of ϕ_{SB} should be used. The choice of the sheath boundary potential for a specific example is illustrated in Section 19.3.2.

B Field. This option is used to generate particles where magnetic field lines enter the computational space. The particles have weights reduced by the cross product of the boundary normal and the magnetic field direction. The number of particles per volume element must be a square (1, 4, 9,…) as the particles are emitted in a square array from the surface of the boundary elements. The user interface displays the square root of the number of particles per element.

Boundary. Generate a thermal distribution of particles at the problem boundaries. Additional parameters are available on the **Advanced Particle Parameters** dialog box (Section 15.3).

Charge Exchange. Generate particles throughout space with current given by the product of the charge exchange cross section, the neutral density, and the main beam ion density. The main beam ion density is determined from the plume. Each component of the initial velocity is given by $\zeta\sqrt{\frac{2\,e\,0.3448}{m_i}}$, where 0.3448 is 4000 K in electron volts and ζ is a random number between -1 and 1.

The neutral density is either specified in the plume map file or is the sum of the un-ionized propellant from the thrusters, the gas flowing through the neutralizers, and the background gas. At each point in space, the contribution from the thruster is given by the solid angle subtended by the thruster grid, the flow rate and the temperature. The contribution from the neutralizers is given by the flow rate, the temperature, and a factor of $\frac{\cos\psi}{\pi r^2}$. The quantity ψ is the angle between the neutralizer axis and the line of sight from the neutralizer to the point of interest and r is the distance from the neutralizer.

The parameters used to compute the neutral density appear in the plume map file described in Appendix A.

Uniform. For time-dependent problems (Figure 30), a uniform distribution is available for initialization. If the "split" option is chosen, each particle is split into eight outwardly moving particles so as to approximate a thermal distribution. Each new particle has a temperature (to be used for possible later splitting) equal to one-half of the original temperature, with the remaining thermal energy appearing as the kinetic energy of the particles. The velocities have components of $\pm 0.707\sqrt{e\theta/m}$ along each axis in a randomly oriented coordinate system. The splitting is done in the plasma frame of reference in order to simulate the correct momentum and energy distribution for a drifting Maxwellian when transformed back to the spacecraft reference frame.

Boundary Injection. For time dependent problems, particles can be created at the problem boundaries to represent the plasma thermal current. These particles can be split in the same manner as described above for a uniform distribution to account for their thermal distribution. Alternatively, a thermal distribution can be created in the same manner as for Boundary particles above.

Surface. Particles can be created at surface elements to model either charged particle emission from a surface or collection by a detector.

Emitter: The user specifies the emitted current density, the range of angles, and range of kinetic energies at the surface. The emission current is associated with the surface (not the underlying conductor) for charging purposes. Tracked particles returning to spacecraft surfaces are counted as incident tracked particle current, so the emitter facility can be used to study the distribution of the returning emitted particles.

Detector: The detector facility provides a means to accurately sample the environment current to a single surface. The reverse trajectory technique, which takes advantage of the Liouville theorem that the distribution function is constant along a trajectory, is used. In the reverse trajectory approach, particles are created at the detector and tracked backwards to determine where they originated. Trajectories that leave the problem space are assumed to connect to the environment, while trajectories that strike object surfaces or become trapped do not. The current is given by an integral over the distribution of the incident charged particles.[19]

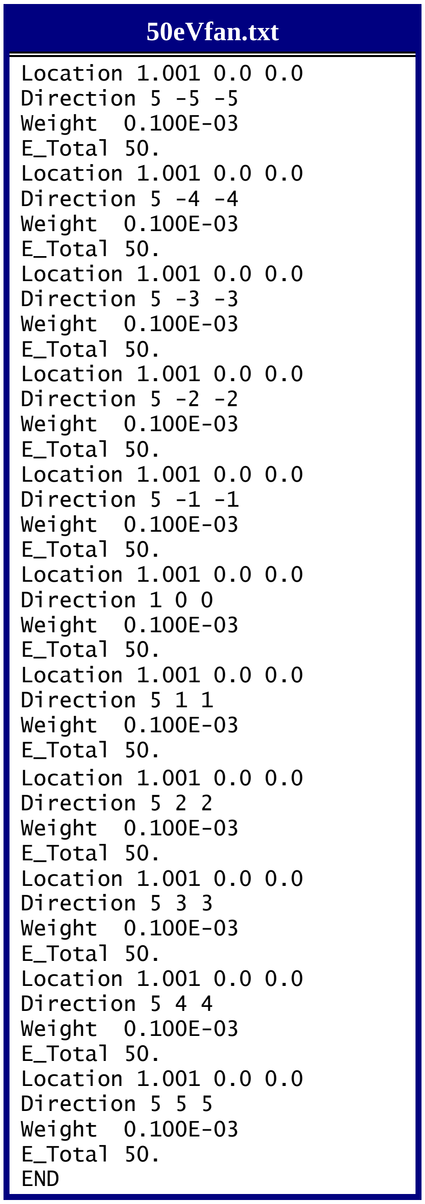
The reverse trajectory method outlined above is in sharp contrast to the sheath current method that is used to calculate the total current to an object and its distribution over the surface. The sheath current method works well when (a) the environment is dense enough to have a sheath, and (b) the object potentials are large compared with the environment temperature. Additionally, it only works for attracted species currents, and due to coarse sampling gives only a crude estimate of the current to any individual surface. It fails completely for surfaces whose current comes from low phase space density portions of the environment. By contrast, the reverse trajectory method can be made to give very accurate results provided care is taken that the high phase space density portion of the ambient environment is well sampled.

External File. When the aforementioned options are inadequate, an external file can be used to specify initial positions and velocities. (See Figure 31 for sample file.) The file format is:

```
LOCATION    x  y  z
DIRECTION   dx dy dz
WEIGHT      weight
ENERGY   energy
LOCATION …
```

where the location is in meters relative to the grid center, the direction need not be normalized, the weight is in amperes, and the energy is kinetic energy in electron volts. Alternatively, the keyword “E_TOTAL” may be used to give the total particle energy. Each such four-line sequence results in definition of a particle. If the “Weight” keyword does not appear, a unit particle weight is assigned. Lines that start with “Comment” are ignored. The user has the option of typing in the filename or browsing to the file. Values for location, direction, weight, and energy that are more than fifteen characters long are read incorrectly.

Particles created from an external file for time dependent problems can be split to account for their thermal distribution. If the initial kinetic energy is less than the temperature, the particles are split in the same manner as described above for a uniform distribution. Otherwise, each particle is split into nine with additional velocity components normal to the initial particle velocity only. There is one zero-velocity central particle and two particles with velocity $\pm 0.866\sqrt{e\theta/m}$ in each of the two randomly oriented coordinate directions normal to the initial particle velocity.

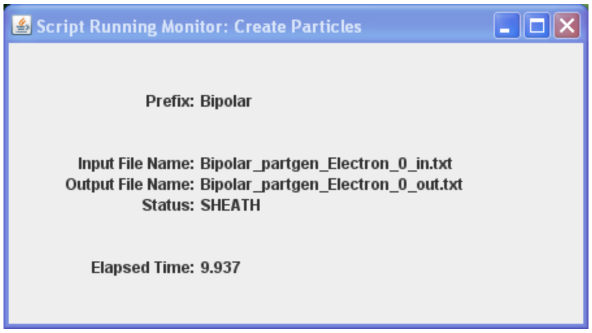


50eVfan.txt

```
Location 1.001 0.0 0.0
Direction 5 -5 -5
Weight  0.100E-03
E_Total 50.
Location 1.001 0.0 0.0
Direction 5 -4 -4
Weight  0.100E-03
E_Total 50.
Location 1.001 0.0 0.0
Direction 5 -3 -3
Weight  0.100E-03
E_Total 50.
Location 1.001 0.0 0.0
Direction 5 -2 -2
Weight  0.100E-03
E_Total 50.
Location 1.001 0.0 0.0
Direction 5 -1 -1
Weight  0.100E-03
E_Total 50.
Location 1.001 0.0 0.0
Direction 1 0 0
Weight  0.100E-03
E_Total 50.
Location 1.001 0.0 0.0
Direction 5 1 1
Weight  0.100E-03
E_Total 50.
Location 1.001 0.0 0.0
Direction 5 2 2
Weight  0.100E-03
E_Total 50.
Location 1.001 0.0 0.0
Direction 5 3 3
Weight  0.100E-03
E_Total 50.
Location 1.001 0.0 0.0
Direction 5 4 4
Weight  0.100E-03
E_Total 50.
Location 1.001 0.0 0.0
Direction 5 5 5
Weight  0.100E-03
E_Total 50.
END
```

Figure 31. Sample External File for Specifying Initial Particle Distribution

Particle generation can be monitored during execution using the **Script Running Monitor** shown in Figure 32.



Prefix: Bipolar

Input File Name: Bipolar_partgen_Electron_0_in.txt
Output File Name: Bipolar_partgen_Electron_0_out.txt
Status: SHEATH

Elapsed Time: 9.937

Figure 32. Script Running Monitor Showing Progress in Particle Generation

15.2 Tracking Particles

Once an initial distribution of particles has been generated, “Track_Particles” is used to track each one of them. Each particle is tracked for a maximum of the “Tracking time per timestep” (on the **Advanced Particle Parameters** dialog box, Figure 34 in Section 15.3). For each timestep, which might be 1 second long for full trajectory tracking, the particle is tracked in substeps that can be no longer than the “Distance a particle can go in one substep” (on the **Advanced Particle Parameters** dialog box, Figure 34), generally 0.1 local mesh units.

Each particle is tracked until one of the following conditions occurs:

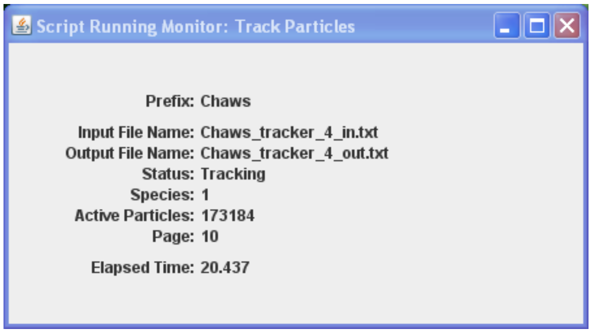
(1) The particle strikes the object.

(2) The particle exits the computational space.

(3) The trajectory time reaches the requested particle tracking time.

(4) The number of substeps exceeds the maximum substep number.

When tracking is complete, *Nascap-2k* writes out the total current to the object and a table apportioning that current by material and conductor in a file with a name like ***prefix*****_tracker_traj_*****iteration#*****_out.txt**. Also, a **Hit** file is created, listing each particle that struck the object with its vital statistics that may be used for additional processing. Tracking can be monitored during execution through the **Script Running Monitor** shown in Figure 33.



Prefix: Chaws
Input File Name: Chaws_tracker_4_in.txt
Output File Name: Chaws_tracker_4_out.txt
Status: Tracking
Species: 1
Active Particles: 173184
Page: 10
Elapsed Time: 20.437

Figure 33. Script Running Monitor Showing Progress in Particle Tracking Calculation

Approved for public release; distribution is unlimited.

Table 15. Input Parameters for Generating and Tracking Particles

PARTICLES		
PARAMETER		DEFINITION
Particle Creation/Initial Particle Distribution for Trajectories		
Contour		Generate particles at the intersection of a cut plane specified in meters from the grid center and a constant potential surface (such as a sheath). (Visualization only, see Section 17.2.)
Sheath		Generate particles representing sheath currents at a constant potential surface.
	Potential Value	Potential defining the "sheath" surface at which particles are generated (V). (Sheath or Contour particles only.)
B Field		Generate particles where magnetic field lines enter the computational space. Only appropriate for electrons.
	Number per cell	Square root of the number of particles emitted on each boundary element surface.
Boundary		Generate a thermal distribution of particles at the problem boundaries.
Charge Exchange		Generate particles throughout space to represent charge exchange ions.
	Cross-section	Charge exchange cross section.
None of the Above		Used when all particles come from an initial uniform distribution, boundary injections, or from an external file.
Uniform		Generate a uniform distribution of particles throughout the grid at problem initialization. (For time dependent problems.)
	Split particles	Divide each newly created particle into eight with velocities that represent the thermal distribution.
Boundary Injection		Generate particles at the problem boundaries. (For time dependent problems.)
	Split particles	Divide each newly created particle into eight with velocities that represent the thermal distribution.
Surface		Generate particles at surface elements.
	Emitter/Detector	Specification of surface elements at which particles are created. Particles created at a detector are for the computation of currents to those surface elements using the reverse trajectory approach. Particles created at an emitter may be used to study the distribution of the escaping and return currents of the emitted particles.
	Current Density	Emitted current density (Am^{-2}). (For emitters only.)
External File		Particle position and velocity information specified in an external file.
	Filename	File used to specify particle position and velocity. (20 characters maximum.)
	Split particles	Divide each newly created particle into eight with velocities that represent the thermal distribution.
Particle Species boxes		Select species to be generated and tracked. Use <control select> to pick multiple species and to unselect species. Double click to change color of trajectory on **Results 3D** tab. Species are defined on the **Environment** tab.
Particle Species		Select species to be generated.
Particle Species for External File		Select species to be generated as specified in an external file. Only applies if external file is specified.
Particle Species for Boundary Injection		Select species to be generated at the problem boundary. Only applies to time dependent problems and if boundary injection is specified.
Tracking time per timestep		The maximum time (sec) a particle is to be tracked. For time-dependent problems without a charging step, the time variable is incremented by this amount.
Advanced		Open **Advanced Particle Parameters** dialog box.

15.3 Particle Advanced Parameters

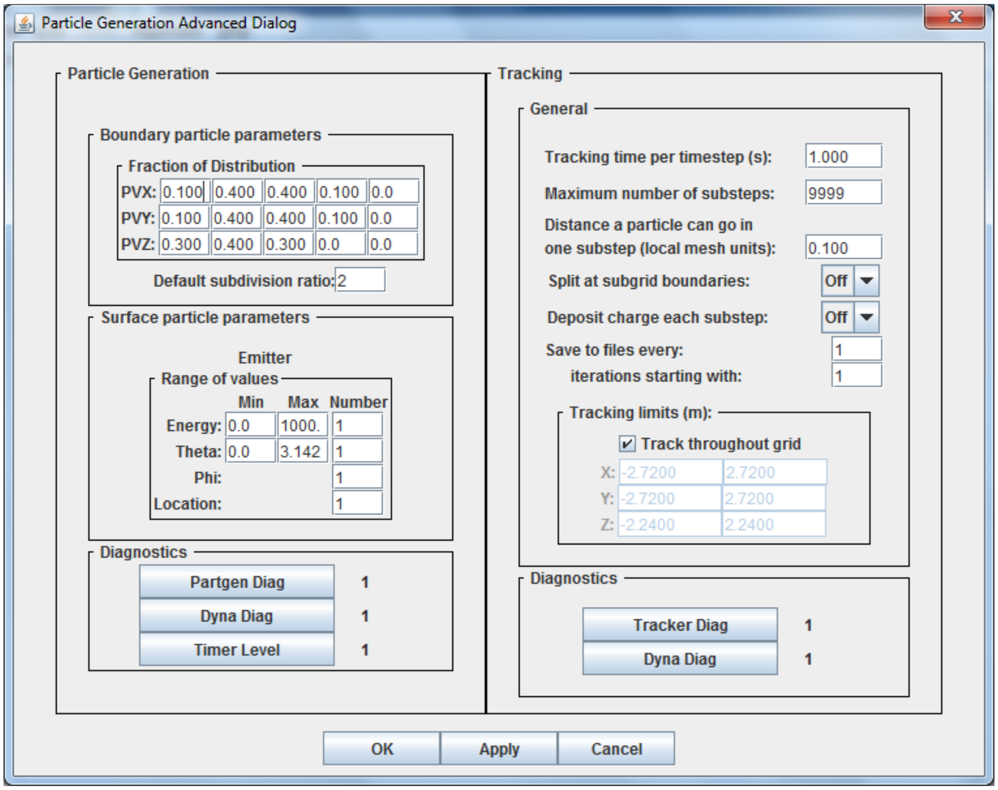
There are two main sections on the **Advanced Particle Parameters** dialog box: “Particle Generation” and “Tracking.” Under “Particle Generation” there are three subsections: “Boundary particle parameters”, “Surface particle parameters”, and “Diagnostics”. The “Boundary particle parameters” are for particles generated with a “Boundary” initial particle distribution. The “Surface particle parameters” are for particles generated at a surface element for an emitter or detector. Under “Tracking” there are two subsections, “General” and “Diagnostics.” To change the value of a diagnostic parameter, click the button until the desired value appears. Table 16 describes the parameters on the **Advanced Particle Parameters** dialog box.

Particles generated using the “Boundary” specification represent particles (typically ram ions) entering the grid from the external space. Particles generated using the “Boundary Injection” specification represent particles thermally flowing into the grid from the external space in time-dependent problems. For each emission point, the thermal distribution of the entering particles may be sampled. For “Boundary Injection” this sampling can be done either by particle splitting or using the distribution parameters. The “Fraction of distribution” parameters specify how the Maxwellian distribution of velocities in each of the three coordinate directions is to be divided. For example, the sequence (0.1, 0.4, 0.5) specifies three particles representing respectively 10% of the distribution on the negative tail, 40% of the distribution constituting the bulk of the negative velocity particles, and the half of the particles with positive velocity. The mean velocity (e.g., ram ion velocity) is added to the thermal velocity. (Note that the number of particles may add up fast: 4 divisions in each of VX, VY times 3 divisions in VZ gives 48 particles per emission point.)

The density of particles generated along the problem boundaries is specified by the default subdivision ratio. Boundary elements are subdivided by the specified factor and particles are generated at the center of the exterior surface of each boundary subelement. For example, if the primary grid is 14 grid units in the Z-direction and a default ratio of “2” is specified, particles would be created for the element (3,4,14) at the four emission points (3.25, 4.25, 15), (3.75, 4.25, 15), (3.25, 4.75, 15), and (3.75, 4.75, 15). The code knows to weight the particles by the cosine of the incident angle, and to omit particles whose velocities point out of the grid.

In the “Surface particle parameters” section, the emitter or detector at which particles are created is specified. The range and number of values of the kinetic energy of the particles at the surface is specified. The “Theta” and “Phi” rows refer to the polar and azimuthal angles of the field of view. The range of the azimuthal angles is always 2π. Particles with the specified range and number of speeds, theta, and phi values are emitted from the specified number of locations. The code may create particles at fewer or additional locations depending on the details of the surface element shape. The number of particles created should be adequate to capture the shape of the distribution function and resolve any shadows or other structure. The total number of particles created is the product of the four values in the “Number” column.

The “split” option under tracking is used to request that each particle be split when it reaches a subgrid boundary. This is to avoid having heavy particles in well-resolved regions. The particle is split only if it carries more charge than a similar particle that has been created in the subgrid and if it has a temperature greater than 0.05 eV. Since the temperature is halved each time a particle is split, this limits the number of times a particle is split.



Particle Generation Advanced Dialog

Particle Generation

Boundary particle parameters

Fraction of Distribution

PVX:	0.100	0.400	0.400	0.100	0.0
PVY:	0.100	0.400	0.400	0.100	0.0
PVZ:	0.300	0.400	0.300	0.0	0.0

Default subdivision ratio: 2

Surface particle parameters

Emitter

Range of values

	Min	Max	Number
Energy:	0.0	1000.	1
Theta:	0.0	3.142	1
Phi:			1
Location:			1

Diagnostics

Partgen Diag 1

Dyna Diag 1

Timer Level 1

Tracking

General

Tracking time per timestep (s): 1.000

Maximum number of substeps: 9999

Distance a particle can go in one substep (local mesh units): 0.100

Split at subgrid boundaries: Off

Deposit charge each substep: Off

Save to files every: 1

iterations starting with: 1

Tracking limits (m):

☑ Track throughout grid

X: -2.7200 2.7200

Y: -2.7200 2.7200

Z: -2.2400 2.2400

Diagnostics

Tracker Diag 1

Dyna Diag 1

Figure 34. Advanced Particle Parameters Dialog Box

Table 16. Input Parameters for the Advanced Particle Parameters Dialog Box

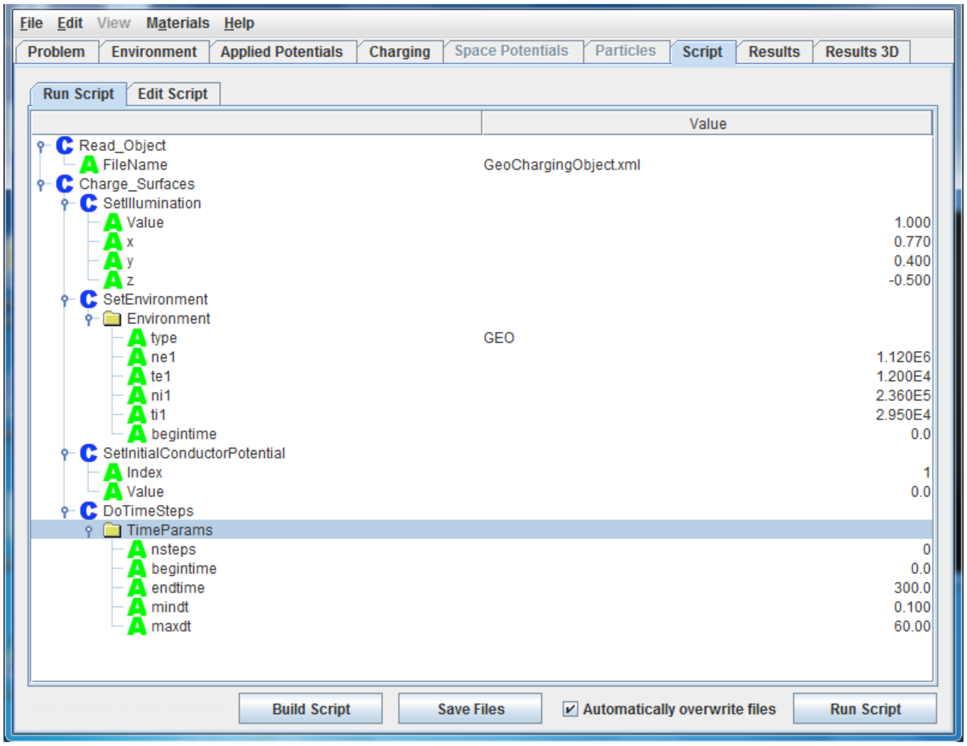
PARTICLE GENERATION AND TRACKING ADVANCED PARAMETERS		
PARAMETER		DEFINITION
Particle Generation		
Boundary Particle Parameters		
	Fraction of Distribution PVX, PVY, and PVZ	Fraction of distribution in each orientation that each particle represents.
	Default subdivision ratio	Ratio by which to subdivide boundary elements before generating particles at centers if no specific value is specified in the table below.
Surface Particle Parameters		
	Emitter/Detector	Name of emitter or detector. (Display only.)
	Energy (Min, Max, Number)	Minimum and Maximum speed of particles at surface and Number of speed values at which to create particles.
	Theta (Min, Max, Number)	Minimum and Maximum polar angle in radians and Number of polar angles at which to create particles.
	Phi (Number)	Number of azimuthal angles at which to create particles.
	Location (Number)	Number of locations on each emitter/detector surface element at which to generate particles.
Diagnostics		
	PartGen Diag, Dyna Diag	Govern optional diagnostic output from various portions of the particle generation process. Level 1 (least) through 5 (most) for each phase of the calculation.
	Timer Level	The frequency of CPU time monitoring.
Tracking		
General		
	Tracking time per timestep	Maximum time (sec) a particle is to be tracked. For time-dependent problems, the time variable is incremented by this amount.
	Maximum number of substeps	Maximum number of substeps per particle per iteration.
	Distance a particle can go in one substep (local mesh units)	Maximum distance (in local grid units) a particle moves during a substep. Substep distances may be less than this value. Electrons gyrating in a magnetic field move only for a fraction of the cyclotron period. Slow ions may move less than “Max Dx” in the tracking time.
	Split at subgrid boundaries	Turn “off” or “on” splitting each particle when it reaches a subgrid boundary.
	Deposit charge each substep	Turn “off” or “on” depositing charge to the grid at each substep in time-dependent problems. If “Off,” the entire charge is placed on the nodes of the volume element in which the particle is located at the end of the timestep.
	Save to files every	How often charge densities are saved in time-dependent problems,
	iterations starting with	starting at this iteration.
Tracking limits		Limits (specified in meters from the center of the grid) of initial particle locations. Particles originating outside these limits are ignored.
Diagnostics		
	Tracker Diag, Dyna Diag	Govern optional diagnostic output from various portions of the tracking process. Level 1 (least) through 5 (most) for each phase of the calculation.

16 Generating and Executing a Script (Script Tab)

The **Script** tab is used to specify and execute the steps of the calculation. There are two subtabs, **Run Script** and **Edit Script**. The script specifies the steps and some of the calculation parameters. This tab is used to construct, view, edit, and run the script.

16.1 Run Script Subtab

Figure 35 shows the **Run Script** subtab with a typical script for a geosynchronous charging calculation followed by the computation of potentials in the space about the spacecraft. The script consists of commands (preceded by a capital “C”), folders (proceeded by a folder icon), and attributes (proceeded by a capital “A”). Attributes are data associated with the command. Each folder contains a set of related attributes.



```
                                                  Value
C Read_Object
    A FileName                                    GeoChargingObject.xml
C Charge_Surfaces
    C SetIllumination
        A Value                                                      1.000
        A x                                                          0.770
        A y                                                          0.400
        A z                                                         -0.500
    C SetEnvironment
        Environment
            A type                                GEO
            A ne1                                                  1.120E6
            A te1                                                  1.200E4
            A ni1                                                  2.360E5
            A ti1                                                  2.950E4
            A begintime                                                0.0
    C SetInitialConductorPotential
        A Index                                                          1
        A Value                                                        0.0
    C DoTimeSteps
        TimeParams
            A nsteps                                                     0
            A begintime                                                0.0
            A endtime                                                300.0
            A mindt                                                  0.100
            A maxdt                                                  60.00
```

Figure 35. Run Script Subtab for a Typical Geosynchronous Charging Problem with Computation of Potentials about Spacecraft

The bottom of the tab displays a message, a checkbox, and three buttons. Clicking the “Build Script” button generates a default script from the “Environment,” “Problem Type,” and parameters specified on the previous tabs. If relevant parameters have changed since the script was last built, the *“The Script is out of date!”* message appears, suggesting that the user *may* want to rebuild the script. Clicking the “Run Script” button instructs *Nascap-2k* to successively execute the script commands. During script execution, the button text changes to “Running.”

Four of the top-level commands have input and output files. During preprocessing, the code uses information on the various tabs to construct the text input files and write them to disk. Then it starts the computational modules. Each module reads its input file, executes using the parameters specified in the input file, and writes a text output file in addition to writing its results into the database. These text output files are discussed in Section 17.3.

If needed, these input files can be edited by the user. The meaning of each of the keywords included in these files is provided in Appendix A. Clicking the “Save Files” button on the bottom of the tab writes out the input files without actually doing the calculations. Unchecking the “Automatically Overwrite Files” checkbox ensures that previously edited input files are not automatically overwritten. The checkbox also applies to the files used when generating particle trajectories for visualization.

16.2 Script Commands

There are several top-level commands available for inclusion in scripts: **Loop, Read Object, Append Object, Initialize Potentials, Charge Surfaces**, **Embed Object in Grid**, **Potentials in Space**, **Static A Field**, **Create Particles**, **Track Particles**, and **Save Files**.

Loop. Execute the enclosed commands the specified number of times, substituting the iteration number for the character “?” in any input or output filename, iteration keyword argument, or directory name.

Table 17. Attributes of Loop Command

KEYWORD	DEFINITION
Iterations	Number of iterations
StartAt	Iteration number for first iteration

Read Object. Reads the XML text file defining the object geometry, materials, initial surface potentials, and other parameters and places the information in the *Nascap-2k* database for use by other commands. Initializes surface potentials.

Table 18. Attribute of Read Object Command

KEYWORD	DEFINITION
FileName	Relative path to XML file

Append Object. The Append Object command adds a second object specified in an XML file to the object in an existing database. See Appendix D for further information.

Table 19. Attributes of Append Object Command

KEYWORD	DEFINITION
FileName	Full path name of XML file to be appended.
X	X offset (m) of appended object.
Y	Y offset (m) of appended object.
Z	Z offset (m) of appended object.

Initialize Potentials. The Initialize Potentials command can be used to reset the surface potentials to their initial values without rereading the object into the database.

Charge Surfaces. Compute time evolution of surface potentials. This command is used to perform surface charging calculations. This module requires that the object had been previously read into the database by the **Read Object** command. **Charge Surfaces** has several second-level commands and no input or output file. Some of the second-level commands, such as "SetIllumination," set parameters needed for surface charging calculations. Some second-level commands, such as "DoTimeSteps," specify the various steps of a surface charging calculation. Other second-level commands, such as "UseTrackedIons," are instructions to the charging code regarding which algorithm to use. Table 20 specifies how each of the available commands is to be used. The "DoTimeSteps," "DoOneTimeStep," and "DoTrackTimeStep" commands are the only ones that write results into the database. Two of the commands, "DoTimeSteps" and "SetEnvironment," require an additional child element (folder of attributes). The command "SetConductorBias" has an optional folder of attributes as a child element.

Table 20. Second-Level Commands of the Charge Surfaces Command and their Attributes

COMMAND/ATTRIBUTE	DEFINITION
SetIllumination	Set sun intensity and direction for surface-charging calculation.
Value	Ratio to solar intensity at Earth’s orbit (1 AU).
X	X component of sun vector.
Y	Y component of sun vector.
Z	Z component of sun vector.
SetEnvironment	Set an environment for surface-charging calculation. Requires at least one “Environment” folder.
SetCustomCurrentDLL	Specifies that surface currents for surface charging calculation are to be obtained from a custom DLL. See Appendix D.
FileName	Name of custom DLL.
ReadPhotoemission	Read photoemission spectral data for surface-charging calculation.
FileName	File in which photoemission spectrum is specified, generally ***prefix*****photo.xml**.
SetVelocity	Set spacecraft velocity in meters per second.
X	X component of spacecraft velocity.
Y	Y component of spacecraft velocity.
Z	Z component of spacecraft velocity.
SetBField	Set value of ambient magnetic field in tesla.
X	X component of magnetic field.
Y	Y component of magnetic field.
Z	Z component of magnetic field.
SetVXBPotentials	Sets $\mathbf{v}\times\mathbf{B}$ potentials on conducting surfaces. Set time to zero.
Value	Initial value of maximum potential in volts.
SetInitialConductorPotential	Set initial value of the potential of a conductor.
Index	Index of conductor.
Value	Initial value of conductor potential in volts.
FixGroundPotential	Fix ground potential to a specified value throughout charging calculation.
Value	Value of ground potential in volts.
SetConductorBias	Set fixed bias value for a conductor.
Value	Value of bias potential in volts.
Index	Index of biased conductor.
Index2	Index of reference conductor.
FourierComponent	Folder specifying the amplitude (V), frequency (Hz), and phase (degrees) of time varying components of bias value. Multiple folders specifying multiple Fourier components are allowed.
Emit Current	Add additional current source to charging calculation.
Index	Conductor number from which current is emitted.
Current	Current emitted in amperes.
UseTrackedCurrent	Use currents generated by particle tracking in computation of surface currents.
UseTrackedIons	Use currents from tracked ions in addition to an analytic expression for the election current in computation of surface currents.

COMMAND/ATTRIBUTE	DEFINITION
SetParameters	
FieldsFromFile	If “On”, use surface electric fields from database in computing limiting of secondaries and photoelectrons. Generally used after Potentials in Space, so that the electric fields calculated by Potentials In Space are used rather than those computed by the Boundary Element Method, which do *not* account for any plasma.
SpaceChargeLimitedPhotoemission	If “On”, use the preliminary model for the space charge barrier height due to photoemitted electrons. Appropriate for near sun environments. See *Nascap-2k Scientific Documentation*.
TransverseCurrent	If “On”, after each timestep, compute transverse currents along surfaces need to achieve change in surface charge density.
ZeroCurDerivAlgorithm	If “On”, perform explicit charging calculation.
ZeroTotCurAlgorithm	If “On”, following a charging timestep, attempt to adjust the overall potential in order to achieve zero net current to the spacecraft.
DoTimeSteps	Perform surface charging calculation for multiple timesteps using time parameters provided. Requires at least one “TimeParams” folder. Uses parameters (surface potentials, environment, and algorithms) set by previously executed commands. Writes surface potentials to database at end of execution.
DoOneTimeStep	Perform one timestep of a surface-charging calculation. Uses parameters (surface potentials, environment, and algorithms) set by previously executed commands. Writes surface potentials to database at end of execution.
Timestep	Timestep duration in seconds.
DoTrackTimeStep	Perform one timestep of a surface-charging calculation. Uses parameters (surface potentials, environment, and algorithms) set by previously executed commands. Writes surface potentials to database at end of execution.
Timestep	Timestep duration in seconds. Same value as “Tracking Time per Timestep” on **Particles** tab/**Time-dependent** subtab.

Table 21. Attributes Contained in “Environment” Folder

Attribute	Value
Type	Allowed values are “GEO,” “LEO,” “Auroral,” “SolarWind,” “Tabular,” and “Custom.”
Ne1	Density (m^{-3}) of electrons of first Maxwellian component of environment. (GEO, LEO, Auroral, SolarWind, Custom.)
Te1	Temperature (eV) of electrons of first Maxwellian component of environment. (GEO, LEO, Auroral, SolarWind, Custom.)
Ni1	Density (m^{-3}) of ions of first Maxwellian component of environment. (GEO, SolarWind, Custom.)
Ti1	Temperature (eV) of ions of first Maxwellian component of environment. (GEO, Auroral, SolarWind, Custom.)
Ne2	Density (m^{-3}) of electrons of second Maxwellian component of environment. (GEO (Double Maxwellian only), Custom.)
Te2	Temperature (eV) of electrons of second Maxwellian component of environment. (GEO (Double Maxwellian only), Auroral, Custom.)
Ni2	Density (m^{-3}) of ions of second Maxwellian component of environment. (GEO (Double Maxwellian only), Custom.)
Ti2	Temperature (eV) of ions of second Maxwellian component of environment. (GEO (Double Maxwellian only), Custom.)
Ke	Kappa parameter for electron Kappa distribution function. (GEO)
Ki	Kappa parameter for ion Kappa distribution function. (GEO)
Curmax	Current (A) in second Maxwellian component of auroral environment. (Auroral.)
Curgaus	Current (A) in Gaussian component of auroral environment. (Auroral.)
Egaus	Center energy (eV) of Gaussian component of auroral environment. (Auroral.)
Widthgaus	Width (eV) of Gaussian component of auroral environment. (Auroral.)
Curpower	Current (A) in Power Law component of auroral environment. (Auroral.)
E1power	Minimum energy (eV) of Power Law component of auroral environment. (Auroral.)
E2power	Maximum energy (eV) of Power Law component of auroral environment. (Auroral.)
Ratepower	Rate used in Power Law component of auroral environment. (Auroral.)
Mass#	Mass (kg) of ion species number #. (LEO, Auroral, SolarWind.)
Fraction#	Fraction of total density in ion species number #. (LEO, Auroral, SolarWind.)
NumSpecies	Number of ion species. (LEO, Auroral, SolarWind.)
electronEnergy#	Energy bin lower edge value. (Tabular)
electronFlux#	Differential flux between electronEnergy# and electronEnergy(#+1)
numEFluxes	Number of electron flux values, and one less than the number of energy values.
ionEnergy#	Energy bin edge value. (Tabular)
ionFlux#	Differential flux between ionEnergy# and ionEnergy(#+1)
numIFluxes	Number of ion flux values, and one less than the number of energy values.
ShadowIons	Set to zero current to sun facing surfaces that are shadowed by other surfaces. Allowed values are “yes” and “no”. (SolarWind)
Begintime	Beginning time of this environment for time-varying environment.
FileName	For “Custom” environment only. Name of custom DLL used to compute charging currents. See Appendix D.

Table 22. Attributes Contained in “TimeParams” Folder

ATTRIBUTE	VALUE
Begintime	Timestamp at beginning of timestep sequence. (Default 0 or previous endtime.)
Endtime	Timestamp at end of timestep sequence. (Default 1.)
Nsteps	Number of timesteps. (Default 1.)
Mindt	Duration of first timestep. (Default 0.1.)
Maxdt	Maximum allowed timestep duration. (Default is no maximum.)

Table 23. Attributes Contained in “FourierComponent” Folder

ATTRIBUTE	VALUE
Amplitude	Amplitude of Fourier component of conductor bias in volts.
Frequency	Frequency of Fourier component of conductor bias in hertz.)
Phase	Phase of Fourier component of conductor bias in degrees.)

Embed Object in Grid. Construct matrix elements used to solve Poisson’s equation for potentials in space. The **Embed Object in Grid** module requires that the object had been previous read into the database by the **Read Object** command and that a grid file, ***prefix*.grd**, exists. It creates the ***prefix*.NBS** and ***prefix*.NME** files and writes into the ***prefix*.NDB** file. This module must be rerun every time either the grid or the object geometry is changed. While the user is not required to delete existing files before execution, strange results are often eliminated when all the database files are deleted before executing this module.

Table 24. Attributes of Embed Object in Grid Command

KEYWORD	DEFINITION
InputFileName	File in which parameters used by module are stored.
OutputFileName	File written by module containing results and diagnostic information.

Potentials in Space. Solve Poisson’s equation for the potential at each grid point using object potential boundary conditions and specified charge density model. This module requires matrix elements computed by **Embed Object in Grid**. It writes into the ***prefix*.NDB** and ***prefix*.NTM** files.

Table 25. Attributes of Potentials in Space Command

KEYWORD	DEFINITION
InputFileName	File where parameters used by module are stored.
OutputFileName	File written by module; contains results and diagnostic information.
Iteration	Integer used to determine the value of some of the parameters written into the input file. Iteration "0" specifies that a geometric wake initialization is performed if the checkbox on the **Space Potentials** tab is checked. Iteration "0" specifies that the space potentials are to be initialized. Therefore, if the requested charge density model is "Full PIC" or "Hybrid PIC," "Laplace" should be used. Also, if the requested charge density model is "Full Trajectory Ions," "Non-linear" should be used. Any value other than "0" specifies that previously computed space potentials are to be used as an initial condition. The value also identifies which "Fraction old potential" specified on the **Space Potentials** tab is to be used.

Static A Field. Use the transverse surface currents computed by **Charge Surfaces**, the volume ion currents computed during particle tracking, and the volume electron currents saved in the database by an external code to compute the magnetic field, the vector potential, and the rate of change of the vector potential from these currents. See the *Nascap-2k Scientific Documentation* for additional details.

Table 26. Attributes of Static A Field Command

KEYWORD	DEFINITION
OutputFileName	File written by module; contains results and diagnostic information.
Timestep	Timestep at which source current values were saved.
Components	Folder of commands that specify which source current terms to use.

Table 27 specifies the attributes contained in the "Components" folder.

Table 27. Attributes Contained in "Components" Folder

ATTRIBUTE	VALUE
Electron	If value is "True," include transverse surface currents as a source in magnetic field and vector potential calculation.
Ion	If value is "True," include volume ion currents as a source in magnetic field and vector potential calculation.
Transverse	If value is "True," include volume electron currents as a source in magnetic field and vector potential calculation.

Create Particles. Create particles for tracking. This module requires the potentials created by the **Potentials in Space** module. The particles are stored in ***prefix*.NPT*nn*** files. Each species has its own file.

This module is also used to create particles tracked for visualization on the **Results 3D** tab. When used for visualization, the only relevant attributes are the input and output file names, which are fixed. The user can edit the input file and view the output file. Particles created for visualization are kept in separate files from those used in calculations.

Table 28. Attributes of Create Particles Command

KEYWORD	DEFINITION
InputFileName	File where parameters used by the module are stored.
OutputFileName	File written by module; contains results and diagnostic information.
Track_mode	Allowed values are "Surface_Currents," "TimeDependent," and "Ion_Density." Specifies from which subtab of the **Particles** tab the parameters for these particles are to be drawn.
Creation_mode	Allowed values are "Uniform," "External," or "Regular." Specifies if the particles created by this command are to be uniformly distributed, specified by an external file, or as indicated by the radio buttons on the relevant subtab.
Species	Name of species to be created. Mass and charge specified on **Environment** tab.
ExecuteEvery	Integer value. Allows for conditional execution. If the iteration step number is evenly divisible by this value, the **Create Particles** command is executed. Only applies within loop.

Track Particles. Compute particle trajectories to determine surface currents and volume charge density. This module requires that the initial positions and velocities have already been created by **Create Particles**. The particle positions and velocities are updated in the ***prefix*.NPT*nn*** files. Surface currents and charge densities in volume elements are saved in the ***prefix*.NDB** file. Historical values are saved in the ***prefix*.NTM** file

This module is also used to track particles for visualization on the **Results 3D** tab. When used for visualization, the only relevant attributes are the input and output file names, which are fixed. The user can edit the input file and view the output file.

Table 29. Attributes of Track Particles Command

KEYWORD	DEFINITION
InputFileName	File where parameters used by the module are stored.
OutputFileName	File written by module; contains results and diagnostic information.
Iteration	Integer that identifies which "Fraction old density" specified on the **Space Potentials** tab is to be used. Ignored if "0."
Track_mode	Allowed values are "Surface_Currents," "TimeDependent," and "Ion_Density." Specifies from which subtab of the **Particles** tab the parameters for these particles are to be drawn.
Update_Time	Allowed values are "Yes" and "No." Indicates if the time should be updated each timestep.
ElectronsOnly	Allowed values are "Yes" and "No." Indicates if resulting charge and current are to be stored in arrays for electron charge and current, for possible use in computations involving both ions and electrons.
ExecuteEvery	Integer value. Allows for conditional execution. If the iteration is evenly divisible by this value, the command is executed. Only applies if within loop.

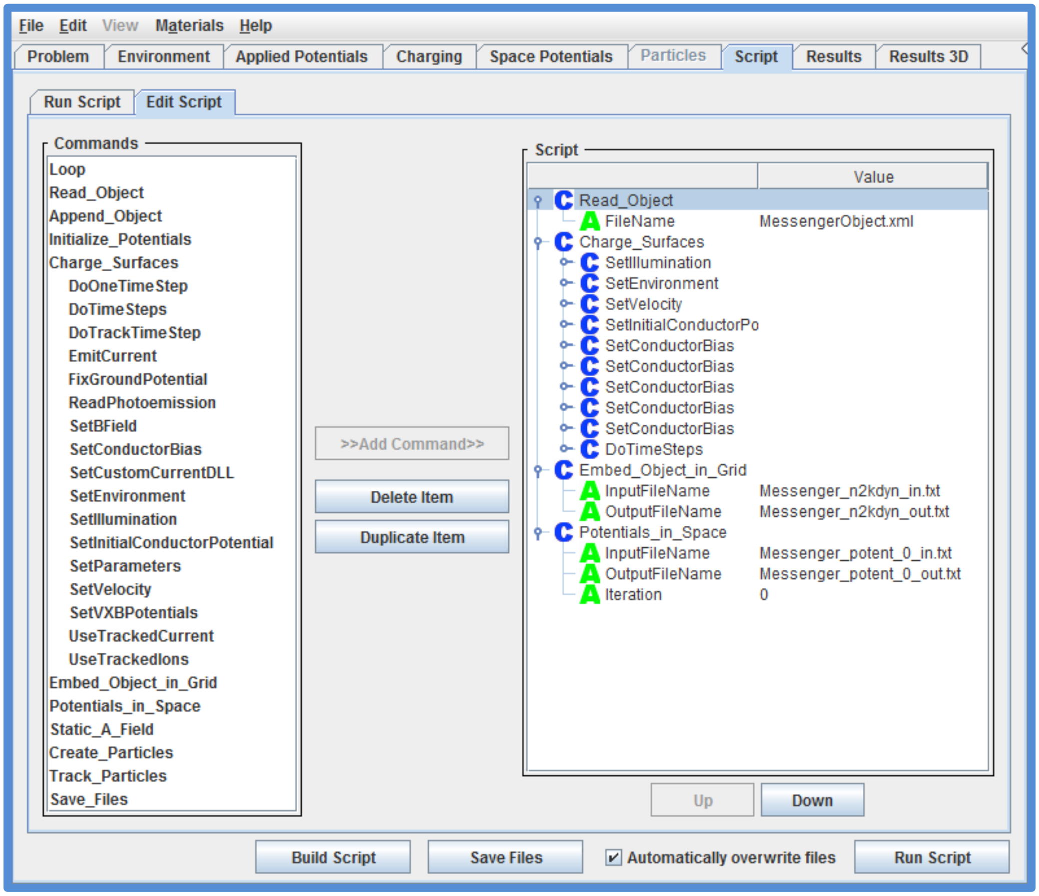
Save Files. Save a copy of all the project files to a specified directory. This command can be useful for plotting or in order to resume the calculation from that point in case of a subsequent error. The relative path name is specified.

Table 30. Attributes of Save Files Command

KEYWORD	DEFINITION
Directory	Directory into which the project files are to be copied.
ExecuteEvery	Integer value. Allows for conditional execution. If the iteration is evenly divisible by this value, the command is executed. Only applies if within loop.

16.3 Edit Script Subtab

The **Edit Script** subtab, shown in Figure 36, is used to modify the script. Caution should be exercised during any script editing. There are no checks to ensure that the resulting script performs as the user intended.



Commands

```
Loop
Read_Object
Append_Object
Initialize_Potentials
Charge_Surfaces
   DoOneTimeStep
   DoTimeSteps
   DoTrackTimeStep
   EmitCurrent
   FixGroundPotential
   ReadPhotoemission
   SetBField
   SetConductorBias
   SetCustomCurrentDLL
   SetEnvironment
   SetIllumination
   SetInitialConductorPotential
   SetParameters
   SetVelocity
   SetVXBPotentials
   UseTrackedCurrent
   UseTrackedIons
Embed_Object_in_Grid
Potentials_in_Space
Static_A_Field
Create_Particles
Track_Particles
Save_Files
```

Script

```
                              Value
C Read_Object
   A FileName                 MessengerObject.xml
C Charge_Surfaces
   C SetIllumination
   C SetEnvironment
   C SetVelocity
   C SetInitialConductorPo
   C SetConductorBias
   C SetConductorBias
   C SetConductorBias
   C SetConductorBias
   C SetConductorBias
   C DoTimeSteps
C Embed_Object_in_Grid
   A InputFileName            Messenger_n2kdyn_in.txt
   A OutputFileName           Messenger_n2kdyn_out.txt
C Potentials_in_Space
   A InputFileName            Messenger_potent_0_in.txt
   A OutputFileName           Messenger_potent_0_out.txt
   A Iteration                0
```

Figure 36. Edit Script Subtab: Making Problem Changes by Directly Modifying the Script

A list of available commands appears in the listbox at the left of the tab, and the script appears on the right. The user can use the buttons to add, delete, and reorder the commands. The value of any attribute may be modified by double-clicking the line and then typing over the old value. The attributes of the first occurrence of each of the “SetIllumination,” “SetEnvironment,” and “DoTimeSteps” commands are the values shown on the **Environment** and **Charging** tabs. Changing the value on the **Script** tab changes the value on the other tab and vice versa.

The script can be saved to or read from an external XML file by using the “Save Script” or “Load Script” selections on the **File** menu. These commands require that the file name is of the form *Script.xml. Adventurous users can edit this file using a text or XML editor.

Table 31. Elements on the Script Tab

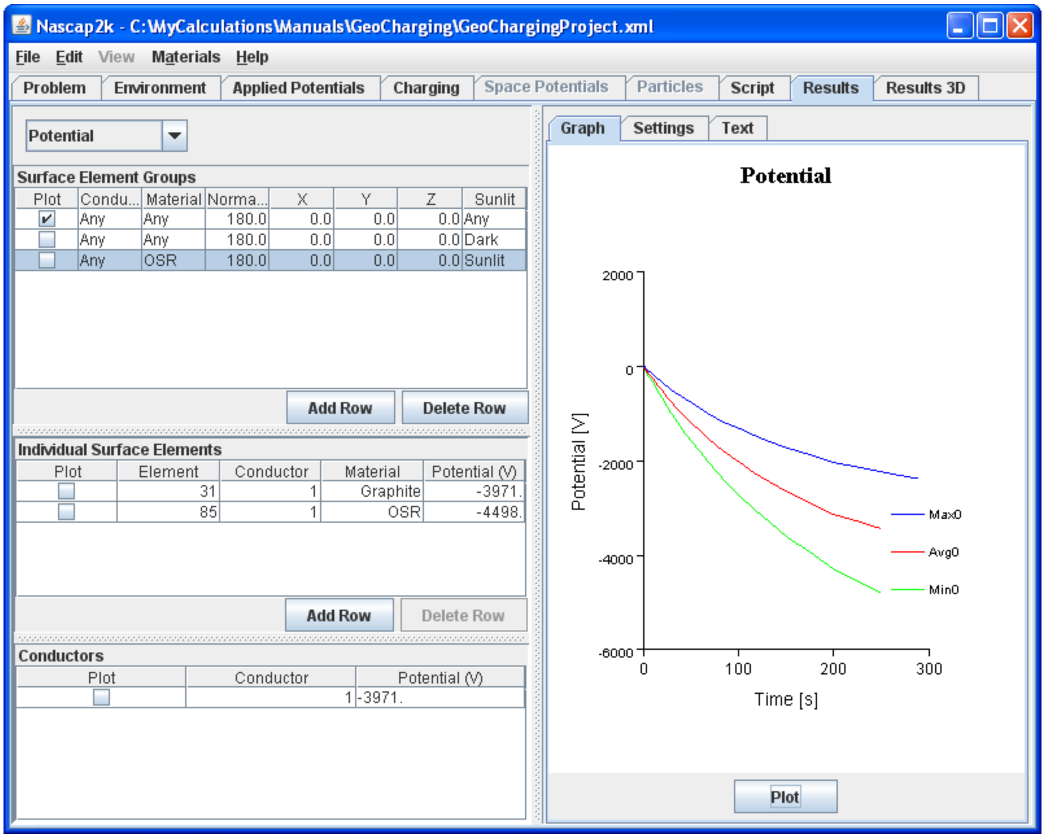
SCRIPT	
COMMAND	**USE**
Run Script subtab	
Script is out of date!	Informs user if any relevant parameters may have been changed since the script was last built.
Build Script	Construct a default script based on the “Environment,” “Problem Type,” and parameters specified on other tabs.
Save Files	Save the input files for all instances of **Embed Object in Grid, Potentials in Space**, **Create Particles**, and **Track Particles** that appear in the script without actually running the script.
Automatically overwrite files	Overwrite existing input files *without* querying the user prior to executing a script. Should *not* be checked if user has edited any of the input files outside the interface.
Run Script	Execute the script. During execution, the button text changes to “Running.”
Edit Script subtab	Used for script editing.
Add Commands	Add highlighted command to script.
Delete Item	Delete highlighted line in script pane.
Duplicate Item	Duplicate highlighted line in script pane, including any second-level commands and attributes.
Up	Move highlighted line up one place in the script pane.
Down	Move highlighted line down one place in the script pane.

17 Viewing Results

17.1 Time-Dependent and Numerical Results (Results Tab)

The **Results** tab is used to obtain the present values and time histories of surface potentials, normal electric fields, and currents. Generally these quantities vary smoothly with time; shorter timesteps can often smooth out any numeric jitters. Time history plots and numeric values may be obtained for groups of surface elements, single surface elements, and conductors using the top, middle, and bottom sections, respectively, on the left side of the tab (Figure 37). Numeric values of the plotted results appear on the **Text** subtab, suitably formatted for copy-and-paste to another plotter or analysis tool.

In the upper left corner of the tab, a drop-down list is used to specify the quantity to be displayed: charging currents, tracked currents, potentials, normal differential potential, electric field, internal electric field or transverse currents. The internal electric field is the differential potential divided by the material thickness. Only available quantities are included in the drop-down list.


Nascap2k - C:\MyCalculations\Manuals\GeoCharging\GeoChargingProject.xml
File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D
Potential
Add Row Delete Row
Add Row Delete Row
Graph Settings Text
Potential
2000
0
-2000
-4000
-6000
0
100
200
300
Potential [V]
Time [s]
Max0
Avg0
Min0
Plot

Surface Element Groups

Plot	Condu...	Material	Norma...	X	Y	Z	Sunlit
☑	Any	Any	180.0	0.0	0.0	0.0	Any
□	Any	Any	180.0	0.0	0.0	0.0	Dark
□	Any	OSR	180.0	0.0	0.0	0.0	Sunlit

Individual Surface Elements

Plot	Element	Conductor	Material	Potential (V)
□	31	1	Graphite	-3971.
□	85	1	OSR	-4498.

Conductors

Plot	Conductor	Potential (V)
□	1	-3971.

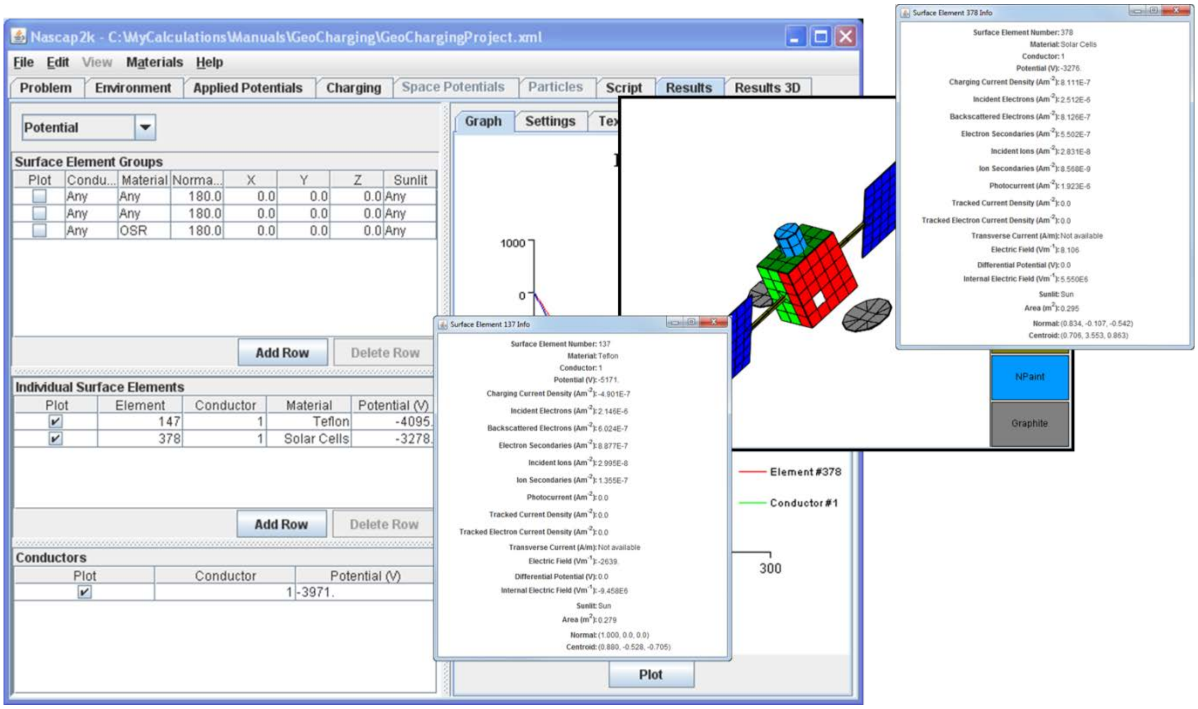
Figure 37. Results Tab: Plotting Minimum, Maximum, and Average Values of Elements with Specified Conductors and/or Materials

Each line in the first section specifies a group of surface elements. All elements matching the specification are included in the group. The selection of elements can be narrowed by specifying that only elements of a single conductor or a single material be included. Elements facing a certain direction can be specified by normal vector and tolerance angle. An element is included if the angle between the normal and the specified vector is less than the specified tolerance. (Thus an angle of 180^o includes all orientations.) The selection of elements can also be narrowed by orientation with respect to the sun. In Figure 38 the potential of all the elements were plotted as a function of time. Because all elements are included in this specification, the minimum, maximum, and average potential values of the elements are displayed. By checking the second row, the user would analyze only those elements pointing away from the sun direction. The third row would produce minimum, maximum, and average potential values for all sunward-facing OSR elements.

Time histories of specific surface elements are plotted using the middle section of the tab as shown in Figure 38. Elements #37 and #62 are shown but not checked. Therefore, they are not plotted. Note that the third and fourth columns automatically display the corresponding conductor number and material. The last column displays the value at the end of the calculation, in this case at t=300 seconds.

The bottom section of the tab may be used to plot values for a specific conductor. The value shown in the last column is the value after the final timestep.

The **Settings** subtab can be accessed to control the axes scales and legend. The **Text** subtab (Figure 39) provides the numerical values that are plotted, which can be copied and pasted into a spreadsheet or other program for further manipulation. The “Display surface numbers of Min and Max” checkbox on the **Settings** subtab specifies that the surface number of the surface with the minimum and the maximum value at each timestep is included in the table on the **Text** subtab.


Nascap2k - C:\MyCalculations\Manuals\GeoCharging\GeoChargingProject.xml
File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D
Potential
Graph Settings Tex
Add Row Delete Row
Add Row Delete Row
Plot
1000
0
300
Element #378
Conductor #1
NPaint
Graphite

Surface Element Groups

Plot	Condu...	Material	Norma...	X	Y	Z	Sunlit
☐	Any	Any	180.0	0.0	0.0	0.0	Any
☐	Any	Any	180.0	0.0	0.0	0.0	Any
☐	Any	OSR	180.0	0.0	0.0	0.0	Any

Individual Surface Elements

Plot	Element	Conductor	Material	Potential (V)
☑	147	1	Teflon	-4095.
☑	378	1	Solar Cells	-3278.

Conductors

Plot	Conductor	Potential (V)
☑	1	-3971.

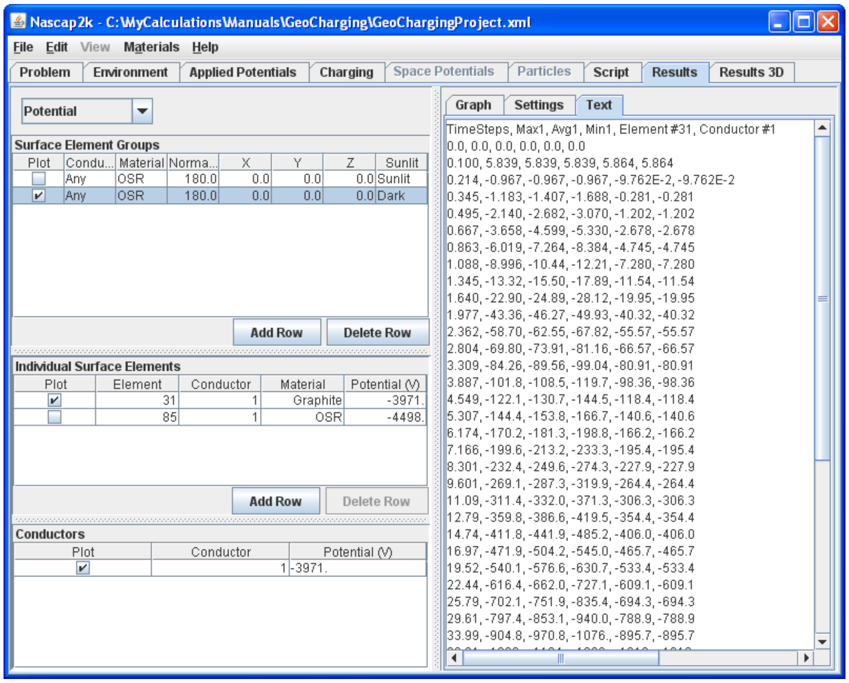
Surface Element 137 Info

Surface Element Number: 137
Material: Teflon
Conductor: 1
Potential (V): -5171.
Charging Current Density (Am^{-2}): -4.901E-7
Incident Electrons (Am^{-2}): 2.146E-6
Backscattered Electrons (Am^{-2}): 6.024E-7
Electron Secondaries (Am^{-2}): 8.877E-7
Incident Ions (Am^{-2}): 2.995E-8
Ion Secondaries (Am^{-2}): 1.355E-7
Photocurrent (Am^{-2}): 0.0
Tracked Current Density (Am^{-2}): 0.0
Tracked Electron Current Density (Am^{-2}): 0.0
Transverse Current (A/m): Not available
Electric Field (Vm^{-1}): -2639.
Differential Potential (V): 0.0
Internal Electric Field (Vm^{-1}): -9.458E6
Sunlit: Sun
Area (m^{2}): 0.279
Normal: (1.000, 0.0, 0.0)
Centroid: (0.880, -0.528, -0.705)

Surface Element 378 Info

Surface Element Number: 378
Material: Solar Cells
Conductor: 1
Potential (V): -3276.
Charging Current Density (Am^{-2}): 8.111E-7
Incident Electrons (Am^{-2}): 2.512E-6
Backscattered Electrons (Am^{-2}): 8.126E-7
Electron Secondaries (Am^{-2}): 5.502E-7
Incident Ions (Am^{-2}): 2.831E-8
Ion Secondaries (Am^{-2}): 8.568E-9
Photocurrent (Am^{-2}): 1.923E-6
Tracked Current Density (Am^{-2}): 0.0
Tracked Electron Current Density (Am^{-2}): 0.0
Transverse Current (A/m): Not available
Electric Field (Vm^{-1}): 8.106
Differential Potential (V): 0.0
Internal Electric Field (Vm^{-1}): 5.550E6
Sunlit: Sun
Area (m^{2}): 0.295
Normal: (0.834, -0.107, -0.542)
Centroid: (0.706, 3.553, 0.863)

Figure 38. Results tab: Plotting Values at Surface Elements


Nascap2k - C:\MyCalculations\Manuals\GeoCharging\GeoChargingProject.xml
File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D
Potential
Graph Settings Text
Add Row Delete Row
Add Row Delete Row

Surface Element Groups

Plot	Condu...	Material	Norma...	X	Y	Z	Sunlit
☐	Any	OSR	180.0	0.0	0.0	0.0	Sunlit
☑	Any	OSR	180.0	0.0	0.0	0.0	Dark

Individual Surface Elements

Plot	Element	Conductor	Material	Potential (V)
☑	31	1	Graphite	-3971.
☐	85	1	OSR	-4498.

Conductors

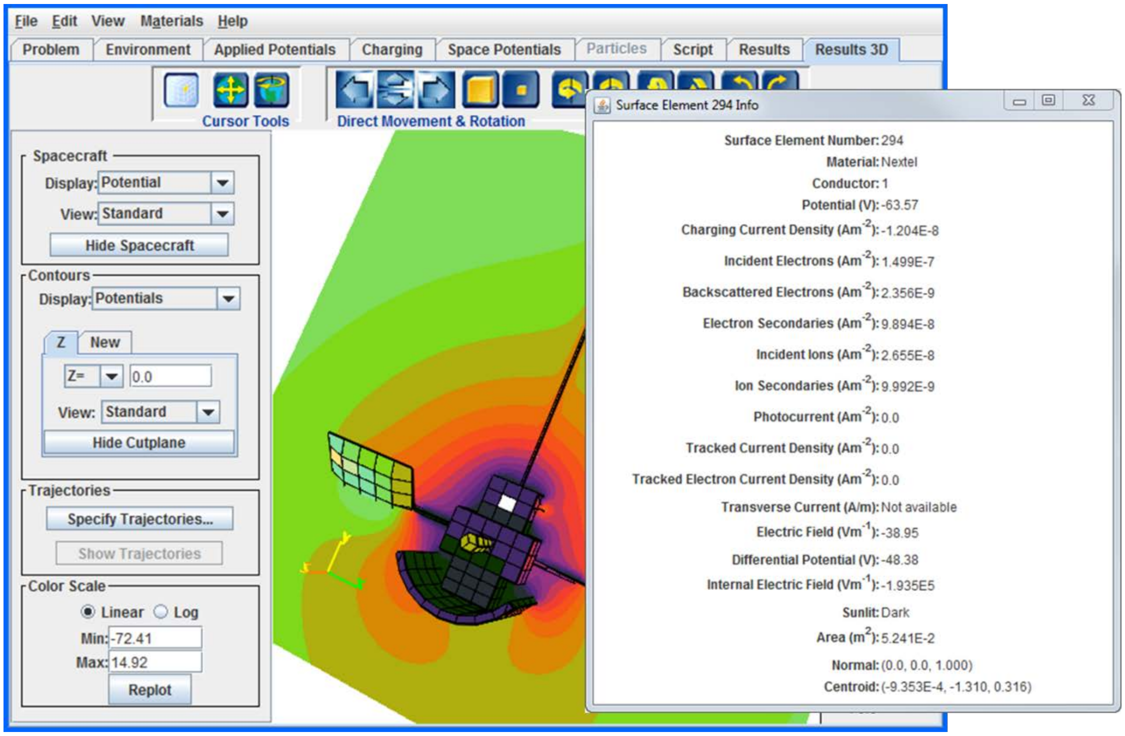
Plot	Conductor	Potential (V)
☑	1	-3971.

```
TimeSteps, Max1, Avg1, Min1, Element #31, Conductor #1
0.0, 0.0, 0.0, 0.0, 0.0, 0.0
0.100, 5.839, 5.839, 5.839, 5.864, 5.864
0.214, -0.967, -0.967, -0.967, -9.762E-2, -9.762E-2
0.345, -1.183, -1.407, -1.688, -0.281, -0.281
0.495, -2.140, -2.682, -3.070, -1.202, -1.202
0.667, -3.658, -4.599, -5.330, -2.678, -2.678
0.863, -6.019, -7.264, -8.384, -4.745, -4.745
1.088, -8.996, -10.44, -12.21, -7.280, -7.280
1.345, -13.32, -15.50, -17.89, -11.54, -11.54
1.640, -22.90, -24.89, -28.12, -19.95, -19.95
1.977, -43.36, -46.27, -49.93, -40.32, -40.32
2.362, -58.70, -62.55, -67.82, -55.57, -55.57
2.804, -69.80, -73.91, -81.16, -66.57, -66.57
3.309, -84.26, -89.56, -99.04, -80.91, -80.91
3.887, -101.8, -108.5, -119.7, -98.36, -98.36
4.549, -122.1, -130.7, -144.5, -118.4, -118.4
5.307, -144.4, -153.8, -166.7, -140.6, -140.6
6.174, -170.2, -181.3, -198.8, -166.2, -166.2
7.166, -199.6, -213.2, -233.3, -195.4, -195.4
8.301, -232.4, -249.6, -274.3, -227.9, -227.9
9.601, -269.1, -287.3, -319.9, -264.4, -264.4
11.09, -311.4, -332.0, -371.3, -306.3, -306.3
12.79, -359.8, -386.6, -419.5, -354.4, -354.4
14.74, -411.8, -441.9, -485.2, -406.0, -406.0
16.97, -471.9, -504.2, -545.0, -465.7, -465.7
19.52, -540.1, -576.6, -630.7, -533.4, -533.4
22.44, -616.4, -662.0, -727.1, -609.1, -609.1
25.79, -702.1, -751.9, -835.4, -694.3, -694.3
29.61, -797.4, -853.1, -940.0, -788.9, -788.9
33.99, -904.8, -970.8, -1076., -895.7, -895.7
```

Figure 39. Text Output in the Results Tab

17.2 Three-Dimensional Results (Results 3D Tab)

The **Results 3D** tab displays results in three dimensions. The **View** menu (see Table 3 in Section 7) can be used to globally adjust the appearance of the display area. As in *Object Toolkit* and *GridTool*, the object may be viewed from a variety of angles and positions using the cursor tools and Direct Movement and Rotation buttons in the same manner as in *Object Toolkit* and *GridTool* (see Table 5 in Section 10.2). As shown in Figure 40, information associated with a specific surface element is displayed using the Surface Element Information tool, . The components of the charging current are not always available. If the ion current is determined by tracking particles, the value used is not always displayed.



Spacecraft Display: Potential
Spacecraft View: Standard
Contours Display: Potentials
Z= 0.0
View: Standard
Color Scale: ● Linear ○ Log
Min: -72.41
Max: 14.92

Surface Element 294 Info

Surface Element Number: 294
Material: Nextel
Conductor: 1
Potential (V): -63.57
Charging Current Density (Am^{-2}): -1.204E-8
Incident Electrons (Am^{-2}): 1.499E-7
Backscattered Electrons (Am^{-2}): 2.356E-9
Electron Secondaries (Am^{-2}): 9.894E-8
Incident Ions (Am^{-2}): 2.655E-8
Ion Secondaries (Am^{-2}): 9.992E-9
Photocurrent (Am^{-2}): 0.0
Tracked Current Density (Am^{-2}): 0.0
Tracked Electron Current Density (Am^{-2}): 0.0
Transverse Current (A/m): Not available
Electric Field (Vm^{-1}): -38.95
Differential Potential (V): -48.38
Internal Electric Field (Vm^{-1}): -1.935E5
Sunlit: Dark
Area (m^{2}): 5.241E-2
Normal: (0.0, 0.0, 1.000)
Centroid: (-9.353E-4, -1.310, 0.316)

Figure 40. Results 3D tab: Displaying Potentials on a Plane through the Center of the Box, Together with Results for a Selected Surface Element

A "Show/Hide" button specifies whether the object is to be displayed or not. The "Display" drop-down list specifies if surface elements are color-coded by surface potential (Figure 41), material, conductor number, charging current, tracked current, differential potential, internal electric field, or normal electric field. Only quantities available are shown in the drop-down list. The "View" drop-down list specifies if the object is to be displayed with a solid color fill with black outlines along element boundaries or with a colored wire frame along element boundaries.

Figure 40 also shows the cut plane capability in the *Nascap-2k* user interface. The specified quantity along surfaces of constant X, Y, or Z can be displayed. The possible quantities are shown in Table 32. Only quantities computed and stored in the database for the selected timestep are shown in the drop-down list. The magnitude and each component of vector quantities may be plotted separately. Values of some quantities are not displayed in special elements (next to the object). Many of the quantities listed in the table are only computed in specialized calculations, such as thruster plume or dynamic PIC.

Table 32. Quantities in Contour Plots

CONTOUR QUANTITIES			
QUANTITY	**NODAL OR ELEMENT-CENTERED**	**SCALAR OR VECTOR**	**MEANING**
Potentials	Nodal	Scalar	Potentials computed by “Potentials in Space” calculation.
Neutral Wake	Element-Centered	Scalar	Geometric wake density. Ambient density is 1.
Electric Field	Nodal	Vector	Electric field computed by “Potentials in Space” calculation.
Ion Plume Density	Element-Centered	Scalar	Density of high-energy main-beam ions from thruster used in thruster plume calculation.
Neutral Plume Density	Element-Centered	Scalar	Density of neutral atoms from unused propellant from the thrusters and neutralizers used in thruster plume calculation.
Charge Exchange Density	Element-Centered	Scalar	Density of ions created by charge exchange computed during tracking.
Ion Density	Element-Centered	Scalar	Density computed during particle tracking.
Electron Density	Element-Centered	Scalar	Density computed during particle tracking.
Ion Current Density	Element-Centered	Vector	Current density computed during particle tracking.
Electron Current Density	Element-Centered	Vector	Current density computed during particle tracking.
Ion Density (Nodal)	Nodal	Scalar	Density computed during particle tracking.
Electron Density (Nodal)	Nodal	Scalar	Density computed during particle tracking.
Current Density (Nodal)	Nodal	Vector	Ion current density computed during particle tracking.
E Current Density (Nodal)	Nodal	Vector	Electron current density computed during particle tracking.
A Field	Element-Centered	Vector	Vector potential from transverse surface and particle currents.
B Field	Element-Centered	Vector	Magnetic field from transverse surface and particle currents.
dAdt	Element-Centered	Vector	Rate of change of the vector potential form the transverse surface and particle currents.
Poynting	Element-Centered	Vector	Poynting vector from cross product of the rate of change of the vector potential and magnetic field.

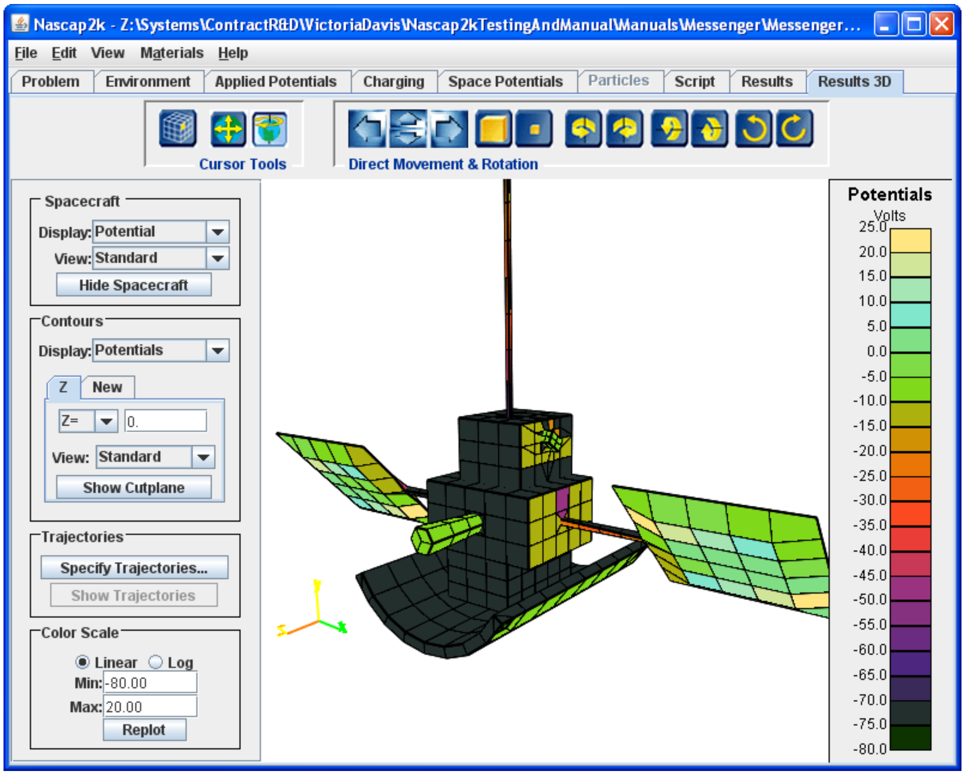
Nodal quantities, such as potentials, are Gouraud shaded. The color of each volume element for element-centered quantities is uniform within the element. The cut plane is specified by the axis to which it is normal and its position, measured in meters, from the center of the grid. The cut planes may be displayed using a Standard view (e.g., as in Figure 40), Wire Frame (e.g., as in Figure 79), or Points. The wire frame view of the contours shows the lines used to construct the plot. Each face of an empty volume element is divided into four squares and additional lines are used to specify the contour levels.

Clicking the “Show/Hide” button specifies that trajectories of selected particles are to be computed and displayed. Clicking the “Specify Trajectories” button opens the **Particle Visualization** dialog box, where the selected particles are specified. This dialog box, shown in Figure 42, is similar to the **Particles** tab with an additional option for specifying the initial particle distribution. “Contour” specifies that particles are to be generated at the intersection of a cut plane and a constant potential surface element (such as a sheath). The color of the trajectory is set by double-clicking the species name. Either trajectories or particle positions can be specified. If “Trajectories” is selected, new particles are created and tracked solely for the purpose of visualization. If “Particles” is selected, the present positions of the particles in the database are shown. The plotting limits are the limits within which particles or trajectories are plotted. If not set (all zeroes) no plot is produced. The tracking limits constrain initial particle locations. Particles originating outside these limits are ignored. If not set (all zeros) all particles are tracked. Table 15 in Section 15.2 lists the input parameters for this dialog box. Figure 43 and Figure 44 are examples of displayed trajectories and particles, respectively. Additional illustrations are provided in Part III.

The code can only display a reasonable number of trajectory segments and stops when there are too many. This can lead to trajectory segments at the outer edge of the grid that are difficult to see. The same problem can occur when plotting particle locations. The “Tracking Limits” parameters can be used to constrain the region of space in which particle trajectories begin.

The “Color Scale” box provides control of scale range, linear or log, and plotting limits (minimum and maximum). Table 33 summarizes the options on the **Results 3D** tab.

Note that running a script deletes any cut plane and trajectory plot objects.


Nascap2k - Z:\Systems\ContractR&D\VictoriaDavis\Nascap2kTestingAndManual\Manuals\Messenger\Messenger…
File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D
Cursor Tools
Direct Movement & Rotation
Hide Spacecraft
Show Cutplane
Specify Trajectories...
Show Trajectories
Replot
Potentials
Volts
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
-55.0
-60.0
-65.0
-70.0
-75.0
-80.0

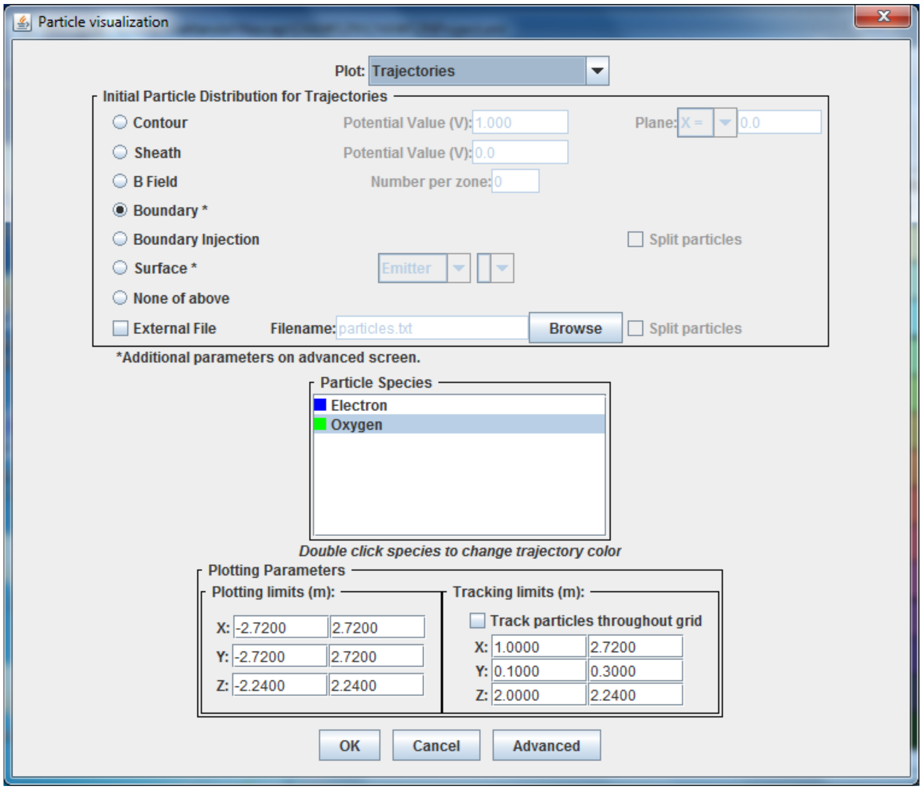
Spacecraft
Display: Potential
View: Standard

Contours
Display: Potentials
Z New
Z= 0.
View: Standard

Trajectories

Color Scale
● Linear ○ Log
Min: -80.00
Max: 20.00

Figure 41. Results 3D: Displaying Potential on the Surface Elements



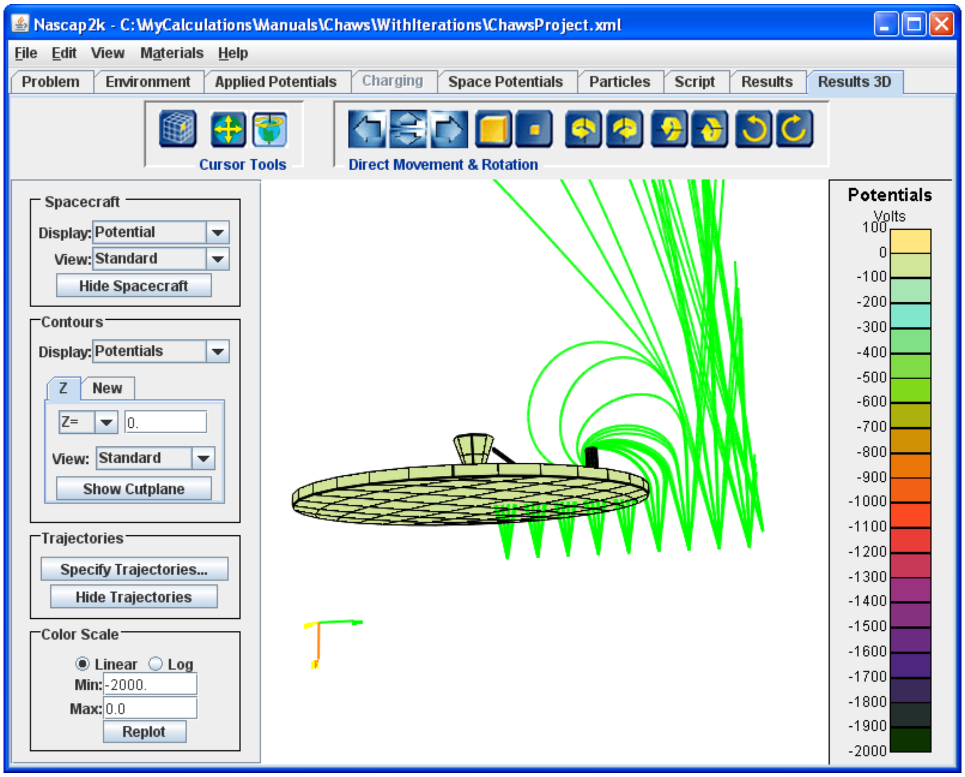
Plot: Trajectories

Initial Particle Distribution for Trajectories
○ Contour Potential Value (V): 1.000 Plane: X = 0.0
○ Sheath Potential Value (V): 0.0
○ B Field Number per zone: 0
● Boundary *
○ Boundary Injection □ Split particles
○ Surface * Emitter
○ None of above
□ External File Filename: particles.txt □ Split particles
*Additional parameters on advanced screen.

Particle Species
Electron
Oxygen
Double click species to change trajectory color

Plotting Parameters
Plotting limits (m):
X: -2.7200 2.7200
Y: -2.7200 2.7200
Z: -2.2400 2.2400
Tracking limits (m):
□ Track particles throughout grid
X: 1.0000 2.7200
Y: 0.1000 0.3000
Z: 2.0000 2.2400

Figure 42. Particle Visualization Dialog Box

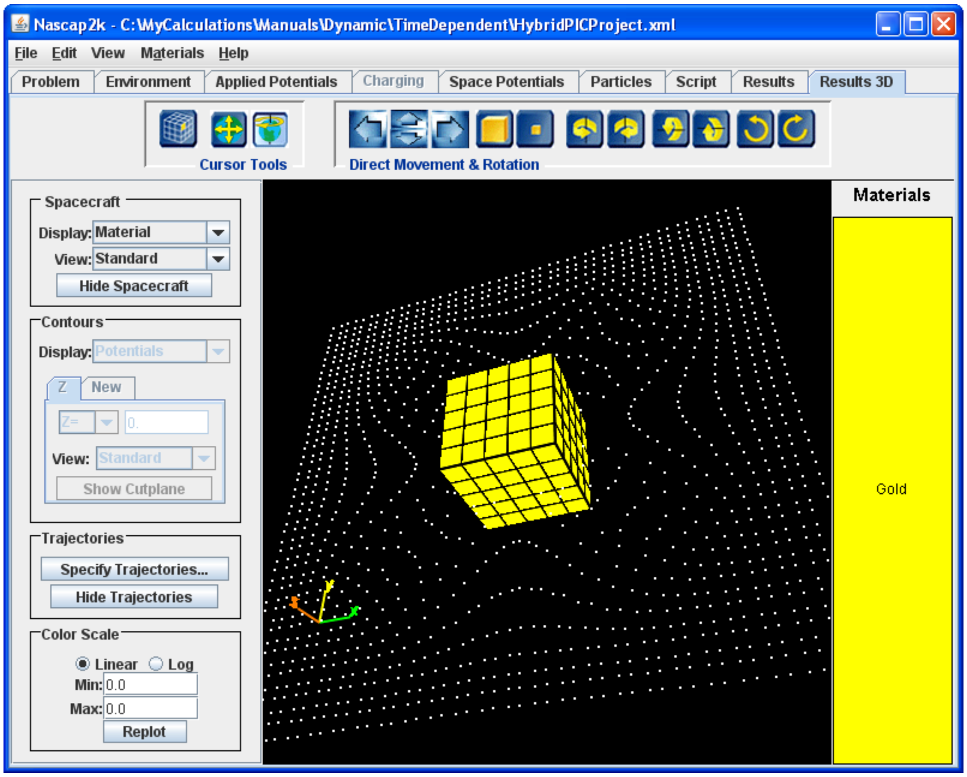

Nascap2k - C:\MyCalculations\Manuals\Chaws\WithIterations\ChawsProject.xml

Spacecraft Display: Potential
View: Standard

Contours Display: Potentials
Z= 0.
View: Standard

Color Scale ● Linear ○ Log
Min: -2000.
Max: 0.0

Figure 43. Selected Particle Trajectories (O+) in "CHAWS" Example


Nascap2k - C:\MyCalculations\Manuals\Dynamic\TimeDependent\HybridPICProject.xml

Spacecraft Display: Material
View: Standard

Contours Display: Potentials
Z= 0.
View: Standard

Color Scale ● Linear ○ Log
Min: 0.0
Max: 0.0

Figure 44. Particle Distribution During Time-dependent Ion Collection by a Negatively Biased Cube

Table 33. Input Parameters for Displaying Results on the Results 3D Tab

RESULTS 3D	
PARAMETER	**DEFINITION**
Spacecraft	
Display	Choice of result to display.
View	Standard: display with a solid color fill. Wire Frame: display with colored frame along surface element boundaries. Points: display using colored points.
Show/Hide	Display or hide results on object surfaces.
Cut Plane	
Display	Choice of result to display.
View	Standard: display with a solid color fill. Wire Frame: display with colored frame along contour boundaries. Points: display using colored points.
Plane	Specifies axis to which the cut plane is normal, and its position (meters) from the center of the grid.
Show/Hide	Display or hide results on a plane in space.
Trajectories	
Specify Trajectories	Open the **Particle Visualization** dialog box (Figure 42).
Show/Hide	Display or hide particle trajectories. Disabled until trajectories are specified.
Color Scale	Plotting control of scale (options are linear or log) and limits.

Table 34. Additional Input Parameters for Displaying Particles. Also See Table 15

PARTICLES	
PARAMETER	**DEFINITION**
Plot	"Trajectories" or "Particle Present Positions." If "Trajectories," generate and display trajectories for the specified initial particle distribution. If "Present Particle Positions," display the positions of existing particles—usually for particle-in-cell calculations—and ignore the initial particle distribution portion of the dialog box.
Initial Particle Distribution for Trajectories	
Contour	Generate particles at the intersection of a cut plane (specified in meters from the grid center) and a constant potential surface (such as a sheath).
Plotting Parameters	
Plotting limits	Set the region of space (specified in meters from center of grid) for which trajectories or particle positions are shown. If no plotting limits are set (all zeroes) no trajectories are generated.
Tracking limits	Limits (specified in meters from the center of the grid) of initial particle locations. Particles originating outside these limits are ignored.
Buttons	
OK	Accept displayed parameters and return to **Results 3D** tab.
Apply	Accept displayed parameters.
Cancel	Return displayed parameters to previous values.

17.3 Output Files

Four of the computational modules, **Embed Object In Grid**, **Potentials in Space**, **Create Particles**, and **Track Particles**, have input and output files. These modules write a text output file in addition to writing results into the database. These output files contain useful information, both computational results and diagnostic information. The amount of diagnostic information is controlled by the diagnostic levels set on the **Advanced Potential Solver Parameters** and **Advanced Particle Parameters** dialog boxes. If a calculation goes awry, the information contained in these files can help diagnose the problem. A description of the most widely used information follows, and a more extensive description is in Appendix A.

17.3.1 Embed Object in Grid

The output file from the execution of the **Embed Object In Grid** module (**N2kDyn_out.txt**) is primarily useful for identifying possible problem areas.

Normal completion is indicated by the following lines at the end of the file.

```
WptTri Called xxxxxxx Times;
WptQud Called yyyyyyy Times.
***TIMER*** Total Elapsed User Time =111957.203 Seconds.
 ***TIMER*** Total Elapsed User Time =111957.250 Seconds.
```

The presence of error messages, indicated by the presence of the string "Error" in the file, may or may not indicate problem regions. The potential solution in volume elements in which error messages occur should be checked for possible problems and the grid modified (usually by additional subdivision) if necessary.

17.3.2 Potentials in Space

Normal completion is indicated by the following lines at the end of the file.
(***prefix*_potent_*iteration#*_out.txt**.)

```
About to close input - unit 5
End Potential Solver.
 ***TIMER*** Total Elapsed User Time = 8118.583 Seconds.
About to return from PSMAIN
```

The appropriate potentials to use for the sheath boundary for each grid appear near the beginning of the output file.

```
Sheath boundary potentials:
 Grid # 1 Ymesh= 1.000000 meters. SthPot= 4.344533 volts.
 Grid # 2 Ymesh= 0.500000 meters. SthPot= 1.724129 volts.
 Grid # 3 Ymesh= 0.250000 meters. SthPot= 0.684221 volts.
 Grid # 4 Ymesh= 0.250000 meters. SthPot= 0.684221 volts.
 Grid # 5 Ymesh= 0.125000 meters. SthPot= 0.271533 volts.
 Grid # 6 Ymesh= 0.125000 meters. SthPot= 0.271533 volts.
```

The most important information in the output file from execution of the **Potentials in Space** module is diagnostic information regarding the convergence of the potential solution. The “RMS Error” and “RDotR” information displayed on the monitor are also written to the file. A complete discussion of these values and other convergence information is in Appendix A. The overall convergence is given by the differences between the new and previous potential solutions, which are expressed as root-mean-square errors and are listed grid by grid.

```
RMS Error for Grid # 1 =  7.0608E-03
RMS Error for Grid # 2 =  8.3624E-01
RMS Error for Grid # 3 =  3.3420E+00
RMS Error for Grid # 4 =  9.5733E-02
RMS Error for Grid # 5 =  3.5733E+00
RMS Error for Grid # 6 =  1.7358E+00
PSMAIN -- space charge iter=  18 rmserr= 2.1303E+00
```

If the root-mean-square errors fail to decrease to an acceptable level, solution-mixing may ameliorate or solve the problem. (See end of Section 14.4.) A particularly large “RMS Error” for a particular grid may or may not indicate a problem in obtaining a solution.

17.3.3 Create Particles

Normal completion is indicated by the following lines at the end of the file.

```
Exiting Particle Generator.
***TIMER*** Total Elapsed User Time = 64241.121 Seconds.
```

A line near the end of the file indicates how many particles were created.

```
GenPa2: found  8005 ELECTRON particles spanning  9 pages.
```

17.3.4 Track Particles

Normal completion is indicated by the following lines at the end of the file (*prefix*_tracker_traj_*iteration#*_out.txt).

```
Exiting Particle Tracker.
***TIMER*** Total Elapsed User Time = 64379.781 Seconds.
```

A table of the current to each material and to each conductor appears near the end of the file. Each entry in the table indicates the current (amperes) collected by the surface elements of the specified material and conductor during the current timestep.

```
   Cond.     ALUM     KAPT     GRAP     GOLD     Total
      1   -1.3E-07 -1.3E-08  0.0E+00  0.0E+00 -1.465E-07
      2    0.0E+00  0.0E+00  0.0E+00 -1.1E-01 -1.141E-01
      3    0.0E+00 -6.8E-07 -1.1E-05  0.0E+00 -1.204E-05
      4    0.0E+00  0.0E+00 -2.8E-06  0.0E+00 -2.847E-06
      5    0.0E+00  0.0E+00 -1.9E-06  0.0E+00 -1.855E-06
      6    0.0E+00  0.0E+00 -5.1E-06  0.0E+00 -5.101E-06
      7    0.0E+00  0.0E+00 -8.0E-05  0.0E+00 -7.951E-05
      8    0.0E+00  0.0E+00 -5.4E-03  0.0E+00 -5.422E-03
  Total   -1.3E-07 -6.9E-07 -5.5E-03 -1.1E-01 -1.196E-01
```

Historical currents, relevant to time dependent calculations, are listed at the very end of the file.

```
ITime     Dt       Time     Collected    Lost      Trapped     Other    Saved
 -----     --       ----     ---------    ----      -------     -----    -----
    1   1.00E-06   1.00E-06   7.76E-05   0.00E+00   0.00E+00   0.00E+00    T
    2   1.00E-06   2.00E-06   1.88E-04   0.00E+00   0.00E+00   0.00E+00    F
    3   1.00E-06   3.00E-06   2.31E-04   0.00E+00   0.00E+00   0.00E+00    F
    4   1.00E-06   4.00E-06   2.58E-04   0.00E+00   0.00E+00   0.00E+00    T
    5   1.00E-06   5.00E-06   2.85E-04   0.00E+00   0.00E+00   0.00E+00    F
    6   1.00E-06   6.00E-06   3.09E-04   0.00E+00   0.00E+00   0.00E+00    F
    7   1.00E-06   7.00E-06   3.08E-04   0.00E+00   0.00E+00   0.00E+00    T
    8   1.00E-06   8.00E-06   3.20E-04   0.00E+00   0.00E+00   0.00E+00    F
    9   1.00E-06   9.00E-06   2.91E-04   0.00E+00   0.00E+00   0.00E+00    F
   10   1.00E-06   1.00E-05   2.97E-04   0.00E+00   0.00E+00   0.00E+00    T
   11   1.00E-06   1.10E-05   3.07E-04   0.00E+00   0.00E+00   0.00E+00    F
   12   1.00E-06   1.20E-05   2.44E-04   0.00E+00   0.00E+00   0.00E+00    F
   13   1.00E-06   1.30E-05   3.06E-04   0.00E+00   0.00E+00   0.00E+00    T
   14   1.00E-06   1.40E-05   2.69E-04   0.00E+00   0.00E+00   0.00E+00    F
   15   1.00E-06   1.50E-05   2.68E-04   0.00E+00   0.00E+00   0.00E+00    F
   16   1.00E-06   1.60E-05   2.43E-04   0.00E+00   0.00E+00   0.00E+00    T
   17   1.00E-06   1.70E-05   2.33E-04   0.00E+00   0.00E+00   0.00E+00    F
   18   1.00E-06   1.80E-05   2.61E-04   0.00E+00   0.00E+00   0.00E+00    F
   19   1.00E-06   1.90E-05   2.36E-04   0.00E+00   0.00E+00   0.00E+00    T
    0   0.00E+00   0.00E+00   0.00E+00   0.00E+00   0.00E+00   0.00E+00    F
   20   1.00E-06   2.00E-05   2.31E-04   0.00E+00   0.00E+00   0.00E+00    F
```

Particle tracking proceeds grid by grid, iterating through all particles that start in each grid. A summary of the status of all the particles is listed after every grid.

```
Trackr: total of     8241 new particles.            Weight: -5.8023E-02
                       2117 were partially tracked.   Weight: -2.3377E-02
                        591 were dead.                Weight: -9.4114E-03
                       5110 went off primary grid.    Weight: -2.1547E-02
                          0 were trapped.             Weight:  0.0000E+00
                        423 with unknown status.      Weight: -3.6869E-03
```

The “new” particles are those that were created since the last time particles were tracked. The “partially tracked” particles are those that have not yet been tracked. The “dead” particles are those that hit the object. The particles that “went off primary grid” are those that left the computational space. The “trapped” category is not used. Particles classified as “unknown” have most likely exceeded the maximum number of substeps (e.g., because they are trapped by a magnetic field).

The particle weights generally are proportional to the current they represent. For PIC type problems (particles created by “Uniform” and “Boundary Injection”) the weights are proportional to their charge. Particles created using “Contour” or “Surface/Detector” have weights that are not easily interpreted. The weights of particles read from an external file are specified in the file.

18 Spacecraft Charging in a Tenuous Plasma (example name: “GeoCharging”)

18.1 Background

The basic physics background on spacecraft charging is provided in Section 13. In this first example *Nascap-2k* is used to compute charging of a simple spacecraft at geosynchronous altitude. The calculation provides the history of surface potentials and fluxes during charging under different conditions in a “Worst Case” geosynchronous environment.

18.2 Object Definition

A simple spacecraft is depicted in Figure 45. The sun is taken to be incident on the spacecraft from the (0.77, 0.4, -0.5) direction in the spacecraft coordinate system. This is appropriate to a spacecraft in geosynchronous orbit at 0^o longitude and Universal time of 8 hours, 10 minutes, and 0 seconds, on day 360 (December 26) of 2002. (The *SEE Interactive Spacecraft Charging Handbook* computes the incident sun angle for geosynchronous spacecraft at 0^o latitude as a function of day and time.) The *Object Toolkit* model of the spacecraft depicting materials and conductors as displayed in *Nascap-2k* is shown in Figure 46. Notice that sun-pointing required a 33-degree (counterclockwise from the +z-axis) array twist.

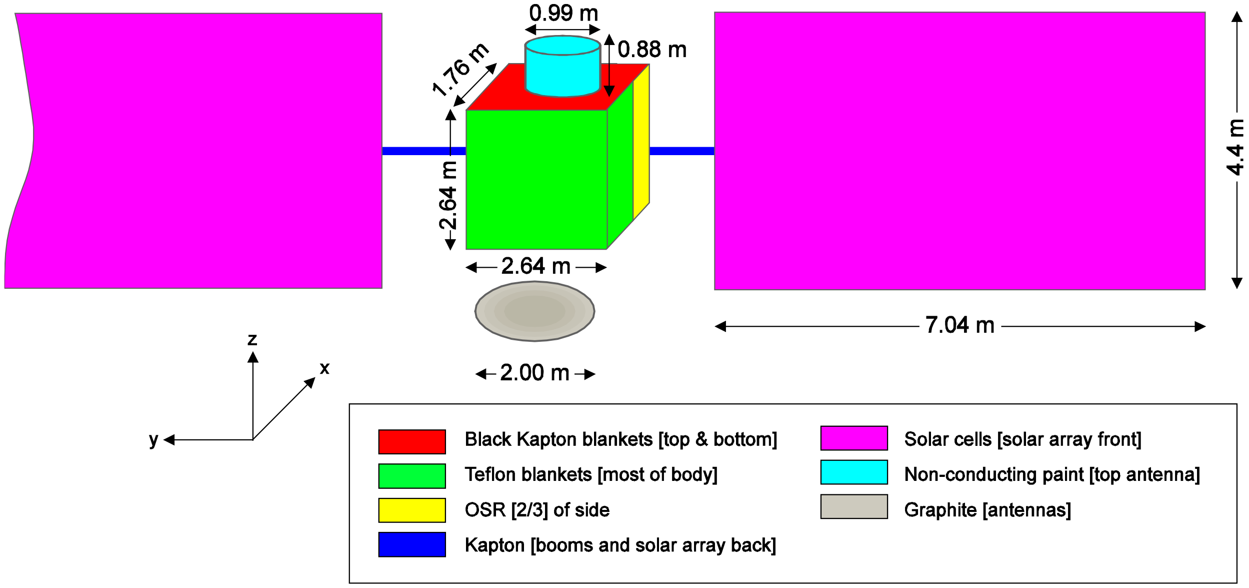
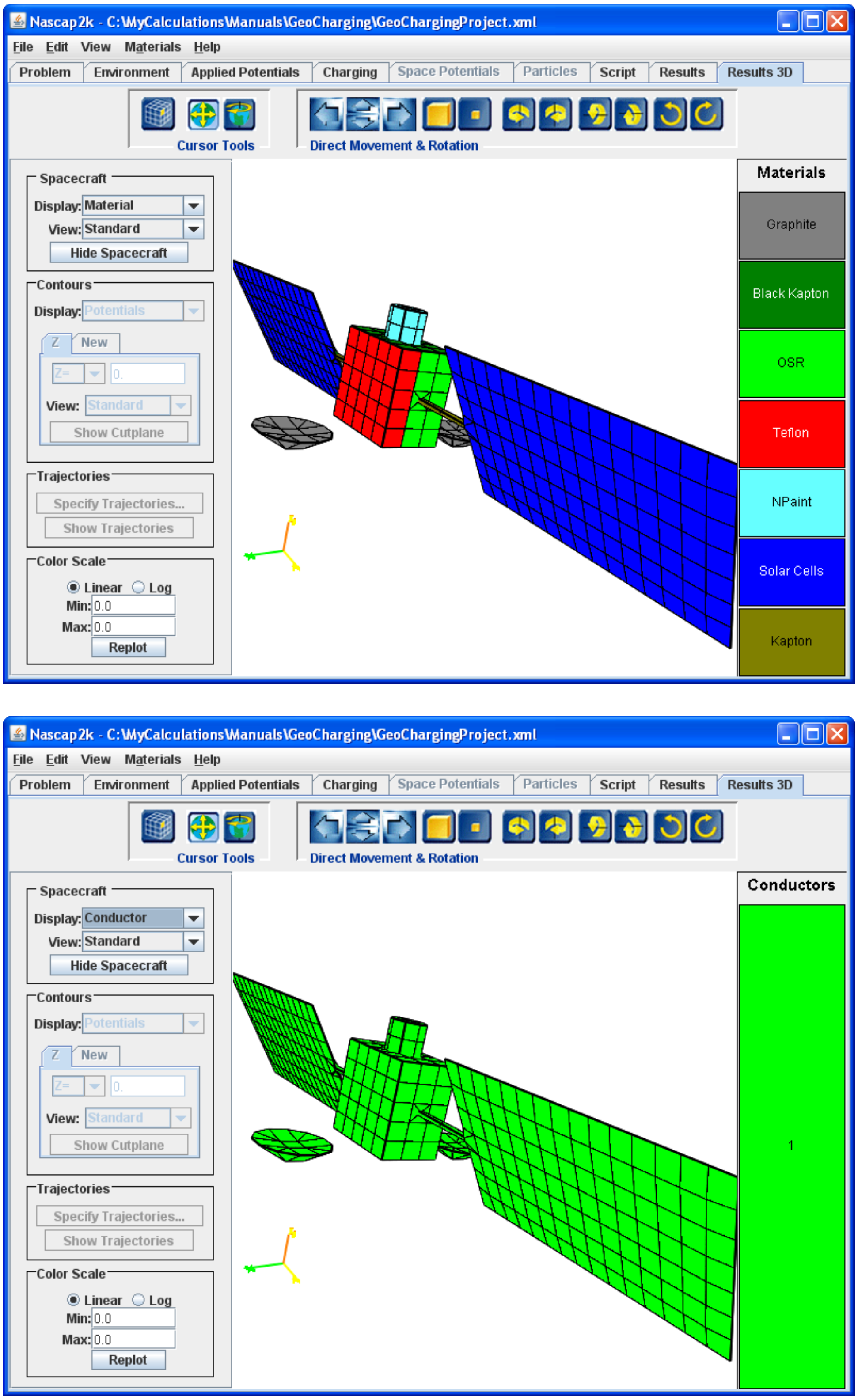

0.99 m
0.88 m
1.76 m
2.64 m
2.64 m
4.4 m
7.04 m
2.00 m
z
x
y
Black Kapton blankets [top & bottom]
Teflon blankets [most of body]
OSR [2/3] of side
Kapton [booms and solar array back]
Solar cells [solar array front]
Non-conducting paint [top antenna]
Graphite [antennas]

Figure 45. Illustrative Spacecraft for Sample Charging Calculation Using *Nascap-2k*



Nascap2k - C:\MyCalculations\Manuals\GeoCharging\GeoChargingProject.xml

Spacecraft
Display: Material
View: Standard

Contours
Display: Potentials
Z= 0.
View: Standard

Color Scale
● Linear ○ Log
Min: 0.0
Max: 0.0

Materials
Graphite
Black Kapton
OSR
Teflon
NPaint
Solar Cells
Kapton

Nascap2k - C:\MyCalculations\Manuals\GeoCharging\GeoChargingProject.xml

Spacecraft
Display: Conductor
View: Standard

Contours
Display: Potentials
Z= 0.
View: Standard

Color Scale
● Linear ○ Log
Min: 0.0
Max: 0.0

Conductors
1

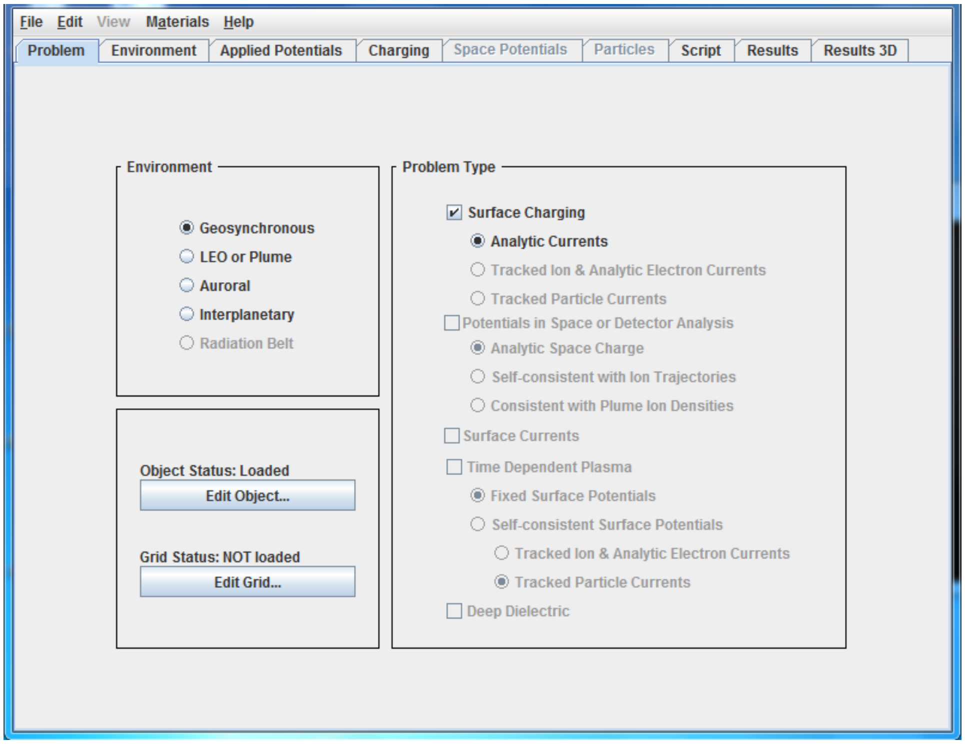
Figure 46. Spacecraft Model Used in the "GeoCharging" Example Showing Material (Top) and Conductor (Bottom) Definition

18.3 Surface Charging Calculation

18.3.1 Case 1: Charging in Sunlight

First, we calculate charging when the spacecraft is sunlit. Start *Nascap*-2k and click “Create New Project.”

Name the new project “GeoCharging” and load the “GeoCharging” object from the **Nascap2k_4/Manual/Example Problems/GeoCharging** folder (GeoChargingObject.xml). On the **Problem** tab, under “Problem Type,” check “Surface Charging.” Figure 47 illustrates the **Problem** tab as it should now look.



Environment

● Geosynchronous
○ LEO or Plume
○ Auroral
○ Interplanetary
○ Radiation Belt

Object Status: Loaded

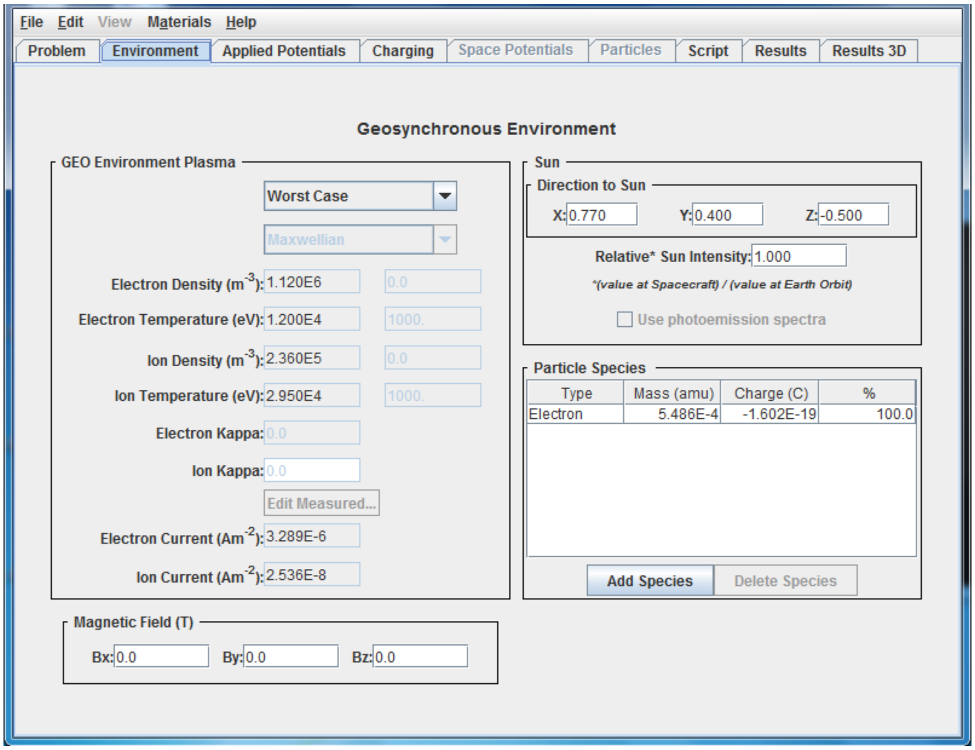
Grid Status: NOT loaded

Problem Type

☑ Surface Charging
● Analytic Currents
○ Tracked Ion & Analytic Electron Currents
○ Tracked Particle Currents
□ Potentials in Space or Detector Analysis
● Analytic Space Charge
○ Self-consistent with Ion Trajectories
○ Consistent with Plume Ion Densities
□ Surface Currents
□ Time Dependent Plasma
● Fixed Surface Potentials
○ Self-consistent Surface Potentials
○ Tracked Ion & Analytic Electron Currents
● Tracked Particle Currents
□ Deep Dielectric

Figure 47. Problem Tab for the “GeoCharging” Example

These calculations use the “Worst Case” environment recommended by the 1984 NASA *Design Guidelines for Assessing and Controlling Spacecraft Charging Effects*[9] for initial modeling during the spacecraft design process. (See Section 11.1.) Click the **Environment** tab, which displays geosynchronous environment parameters. Under “GEO Environment Plasma,” select “Worst Case” from the drop-down menu. Make sure the magnetic field, sun-direction, and relative sun intensity are as shown in Figure 48.


File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D

Geosynchronous Environment

GEO Environment Plasma

Worst Case

Maxwellian

Electron Density (m^{-3}): 1.120E6 | 0.0

Electron Temperature (eV): 1.200E4 | 1000.

Ion Density (m^{-3}): 2.360E5 | 0.0

Ion Temperature (eV): 2.950E4 | 1000.

Electron Kappa: 0.0

Ion Kappa: 0.0

Edit Measured...

Electron Current (Am^{-2}): 3.289E-6

Ion Current (Am^{-2}): 2.536E-8

Sun

Direction to Sun

X: 0.770 Y: 0.400 Z: -0.500

Relative* Sun Intensity: 1.000

*(value at Spacecraft) / (value at Earth Orbit)

□ Use photoemission spectra

Particle Species

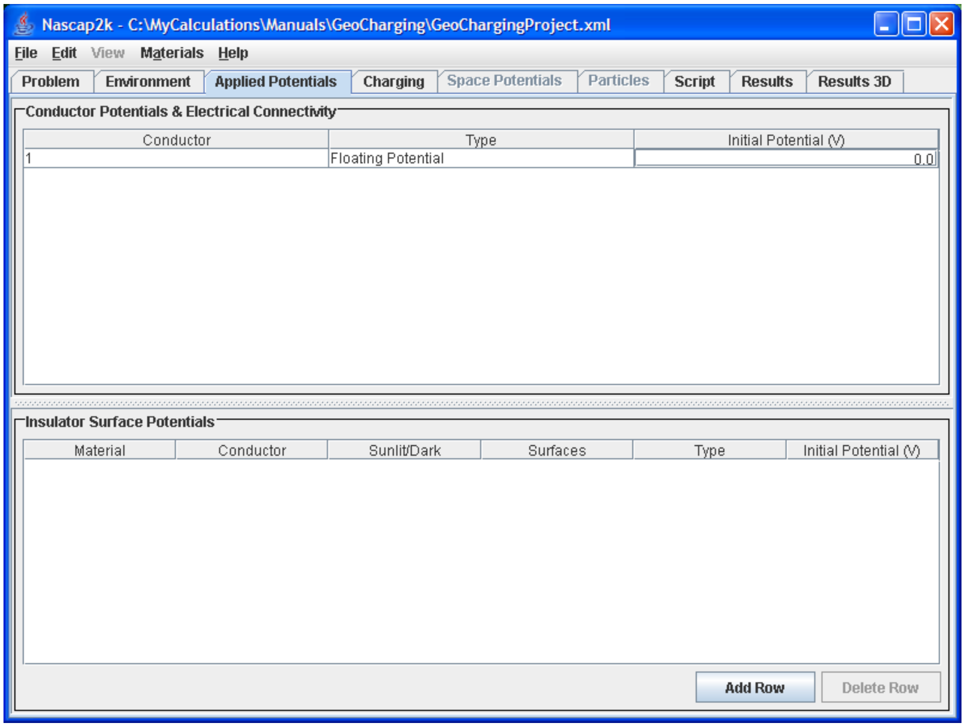
Type	Mass (amu)	Charge (C)	%
Electron	5.486E-4	-1.602E-19	100.0

Magnetic Field (T)

Bx: 0.0 By: 0.0 Bz: 0.0

Figure 48. Geosynchronous Environment Tab for Case 1 of the "GeoCharging" Example

The initial potentials are set to zero on the **Applied Potentials** tab as depicted in Figure 49.


Nascap2k - C:\MyCalculations\Manuals\GeoCharging\GeoChargingProject.xml
File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D

Conductor Potentials & Electrical Connectivity

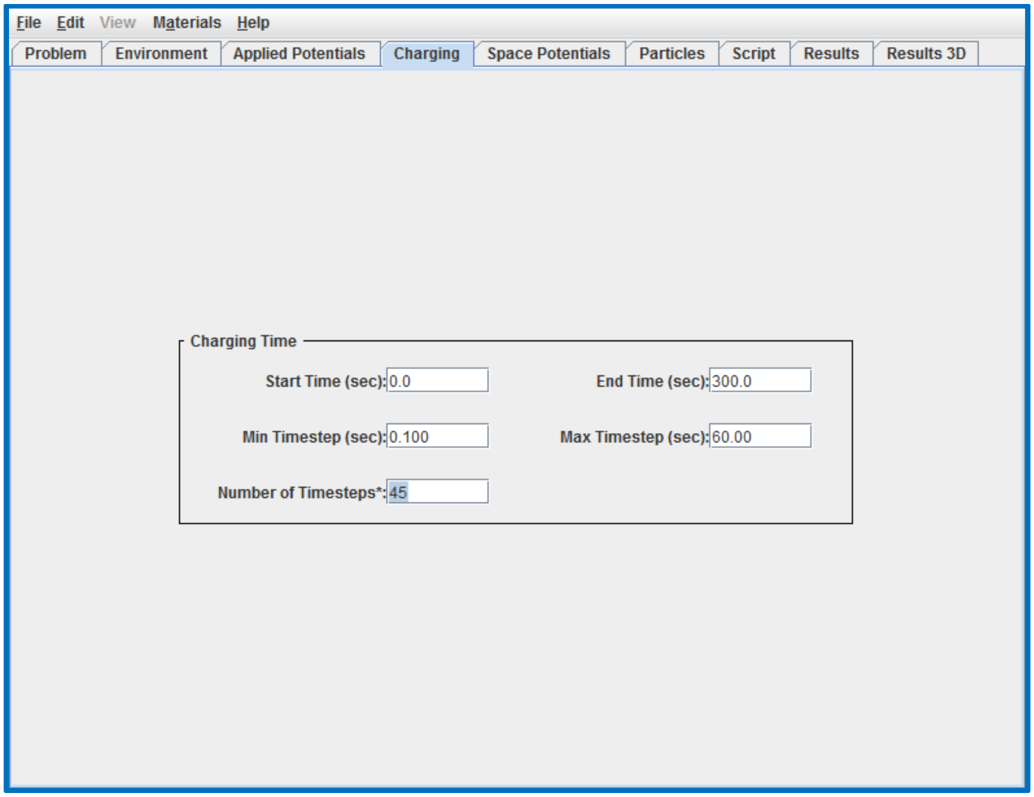
Conductor	Type	Initial Potential (V)
1	Floating Potential	0.0

Insulator Surface Potentials

Material	Conductor	Sunlit/Dark	Surfaces	Type	Initial Potential (V)

Figure 49. Applied Potentials Tab for the "GeoCharging" Example

In Figure 50, the Charging Time parameters are set to allow the spacecraft to charge for 5 minutes using geometrically distributed timesteps. Typically, the longest a spacecraft would be exposed to such a severe environment is 15 minutes.



Charging Time

Start Time (sec): 0.0

End Time (sec): 300.0

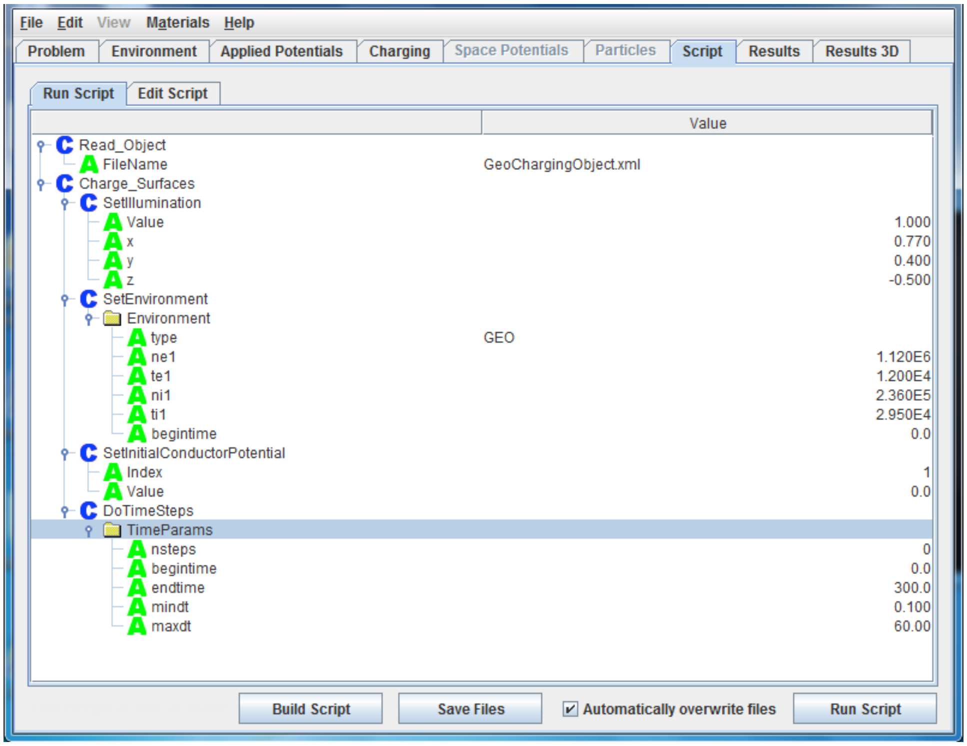
Min Timestep (sec): 0.100

Max Timestep (sec): 60.00

Number of Timesteps*: 45

Figure 50. Charging Tab for the "GeoCharging" Example

Click the **Script** tab. The message *"The Script is out of date!"* appears and there is no script on the page. Click the "Build Script" button. Once the script is created, sublevels in the "Charge Surfaces" script can be opened up by clicking on the particular steps as shown in Figure 51.

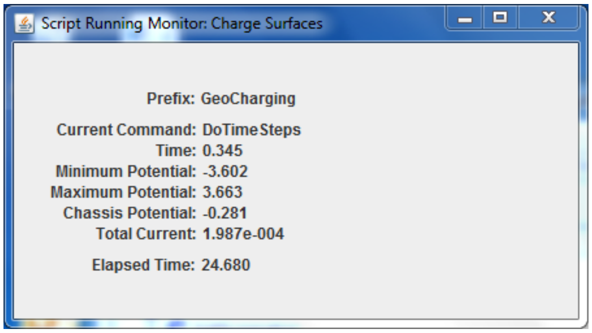


	Value
Read_Object	
FileName	GeoChargingObject.xml
Charge_Surfaces	
SetIllumination	
Value	1.000
x	0.770
y	0.400
z	-0.500
SetEnvironment	
Environment	
type	GEO
ne1	1.120E6
te1	1.200E4
ni1	2.360E5
ti1	2.950E4
begintime	0.0
SetInitialConductorPotential	
Index	1
Value	0.0
DoTimeSteps	
TimeParams	
nsteps	0
begintime	0.0
endtime	300.0
mindt	0.100
maxdt	60.00

☑ Automatically overwrite files

Figure 51. Script for Case 1 of the "GeoCharging" Example

To execute the calculation, click the "Run Script" button. Figure 52 shows a snapshot of the **Script Running Monitor** during the calculation. The monitor's main purpose is to confirm that the calculation is proceeding and indicate its progress. In Figure 52, the calculation has reached 0.345 seconds out of the requested 300 seconds. As the calculation proceeds the "Total Current" should drop a few orders of magnitude from its initial level.



Script Running Monitor: Charge Surfaces

Prefix: GeoCharging

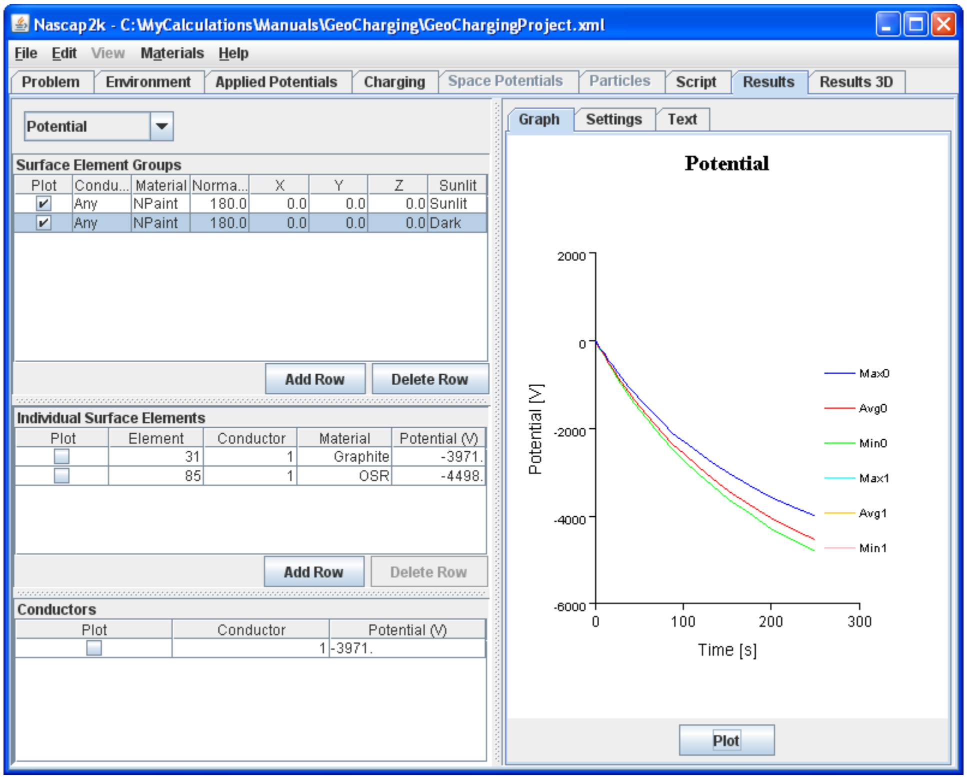
Current Command: DoTimeSteps
Time: 0.345
Minimum Potential: -3.602
Maximum Potential: 3.663
Chassis Potential: -0.281
Total Current: 1.987e-004

Elapsed Time: 24.680

Figure 52. Script Running Monitor During Calculation for Case 1 of the "GeoCharging" Example

Figure 53 through Figure 56 show the results of the calculation as displayed on the **Results** tab. The drop-down list at top-left enables the selection of potentials, electric field, charging currents, or tracked currents. The checkboxes along the left are used to select for which elements the desired quantity appears in the graph on the right. The graph is updated each time the "Plot" button is clicked.

In Figure 53, the "Surface Element Groups" portion of the tab is used to compare the history of potentials of sunlit and dark surface elements of the cylindrical antenna. Specify groups of elements by selecting the conductor number, material, normal direction, and if the elements are sunlit or dark. In the figure, “NPaint” is selected from the drop-down list of materials, while “Sunlit” is selected in the first row and “Dark” in the second. (Note that the “sunlit” category does not account for shadowing by other surfaces, so that some of the “sunlit” surfaces are actually shadowed.) Click the “Add Row” button to create an additional row. When you click the “Plot” button, the minimum, maximum, and average surface potentials for each group are displayed for each timestep. In this case, all the shaded potentials are equal and coincident with the minimum sunlit potential (which is that of the shadowed sun-facing cells).



Surface Element Groups

Plot	Condu...	Material	Norma...	X	Y	Z	Sunlit
☑	Any	NPaint	180.0	0.0	0.0	0.0	Sunlit
☑	Any	NPaint	180.0	0.0	0.0	0.0	Dark

Individual Surface Elements

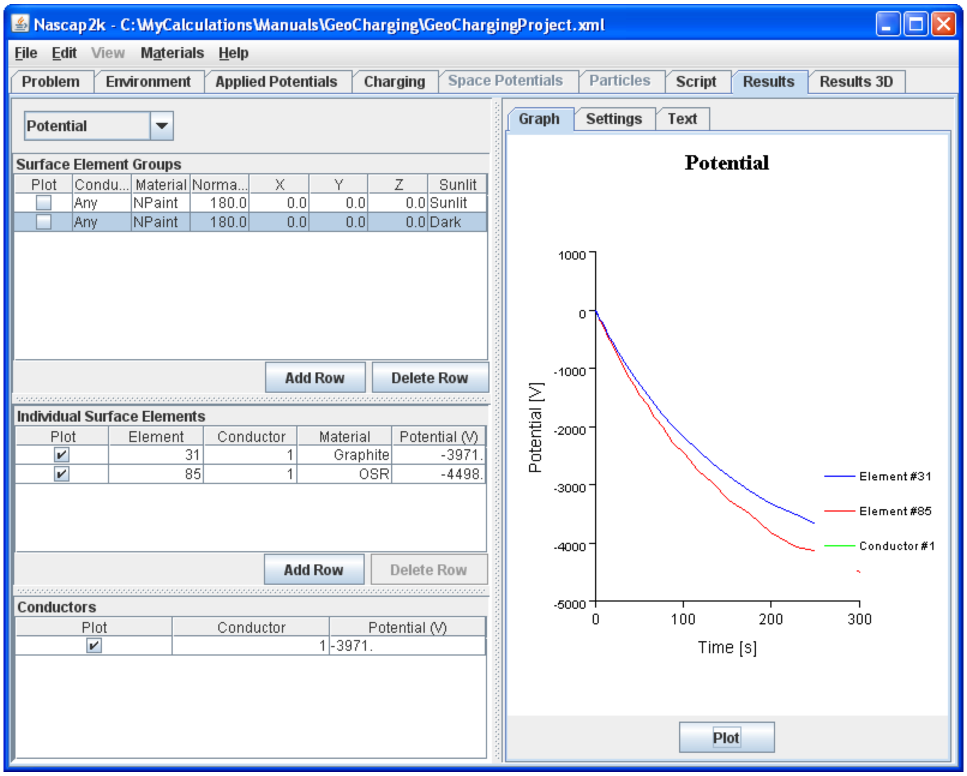
Plot	Element	Conductor	Material	Potential (V)
☐	31	1	Graphite	-3971.
☐	85	1	OSR	-4498.

Conductors

Plot	Conductor	Potential (V)
☐	1	-3971.

Figure 53. Results Tab for Case 1 of the “GeoCharging” Example Comparing Evolution of Potential Between Sunlit and Dark Surface Elements on the Cylindrical Antenna

Potential, electric field, and current-to-individual surface elements may also be compared using the “Individual Surface Elements” section of the tab, as shown in Figure 54. Enter the element number. (The element number of a specific element can be determined on the **Results 3D** tab by clicking on the element when the cursor is in element select mode). Values are automatically added in the “Conductor,” “Material,” and “Potential,” (or “Current” or “Electric field”) fields when the checkbox is checked and the “Plot” button is clicked. The “Potential,” (or “Current” or “Electric field”) value is that at the end of the calculation.



Potential

Surface Element Groups

Plot	Condu...	Material	Norma...	X	Y	Z	Sunlit
□	Any	NPaint	180.0	0.0	0.0	0.0	Sunlit
□	Any	NPaint	180.0	0.0	0.0	0.0	Dark

Individual Surface Elements

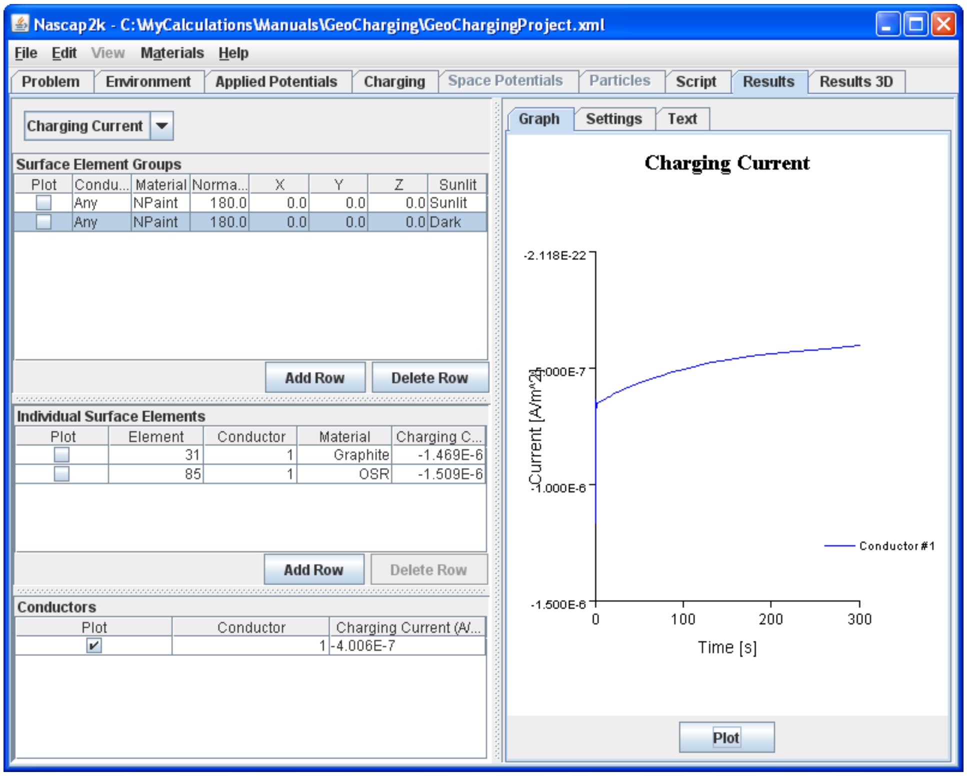
Plot	Element	Conductor	Material	Potential (V)
☑	31	1	Graphite	-3971.
☑	85	1	OSR	-4498.

Conductors

Plot	Conductor	Potential (V)
☑	1	-3971.

Figure 54. Results Tab for Case 1 of the "GeoCharging" Example Comparing Evolution of Potential for Different Surface Elements

Figure 55 shows the mean charging current density to bare cells of a conductor as a function of time. The graph is created by selecting "Charging Current" on the drop-down list and checking the checkboxes next to the conductors in the "Conductors" section at the bottom of the tab. The value for each conductor at the end of the calculation is displayed.



Surface Element Groups

Plot	Condu...	Material	Norma...	X	Y	Z	Sunlit
□	Any	NPaint	180.0	0.0	0.0	0.0	Sunlit
□	Any	NPaint	180.0	0.0	0.0	0.0	Dark

Individual Surface Elements

Plot	Element	Conductor	Material	Charging C...
□	31	1	Graphite	-1.469E-6
□	85	1	OSR	-1.509E-6

Conductors

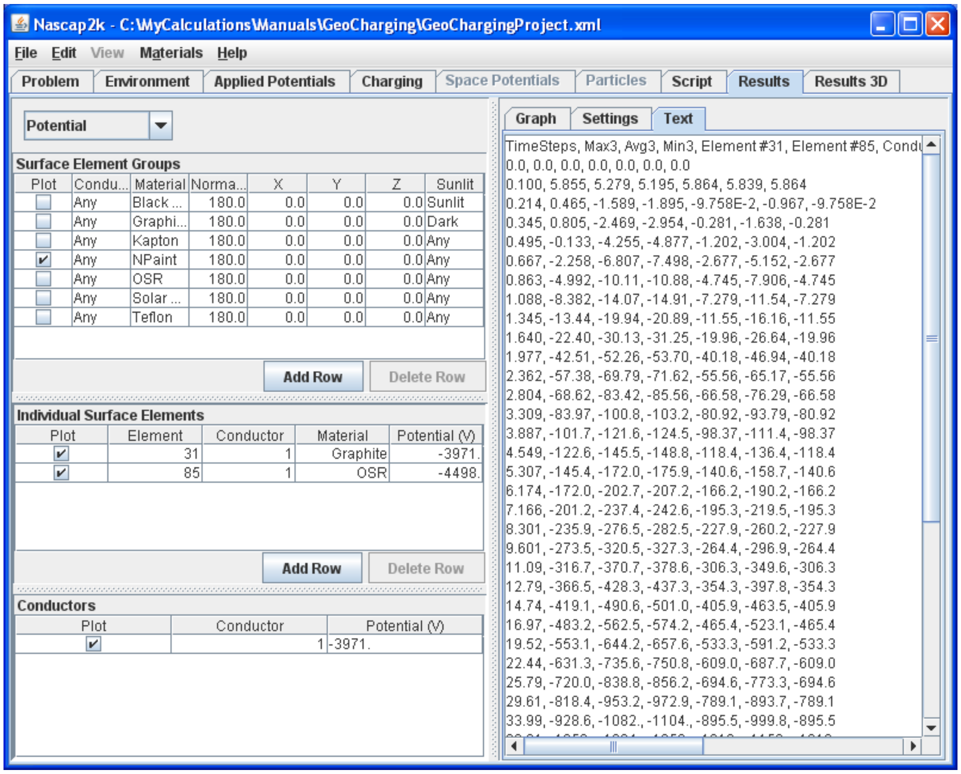
Plot	Conductor	Charging Current (A/...
☑	1	-4.006E-7

Figure 55. Results Tab Showing mean Current density to the Conductor as a Function of time for Case 1 of the "GeoCharging" Example

The **Text** subtab can be used to obtain the difference between the potentials on insulators and those on the underlying conductor(s), as shown in Figure 56. This is an important part of a spacecraft charging calculation that leads to assessments of the likelihood of arcing. Table 35 lists absolute and differential potentials after 300 seconds for Case 1. Because the results are displayed in tabular format they can be copied elsewhere (e.g., a favorite spreadsheet program) for further manipulation, such as assessing the sensitivity of the results on the choice of number of timesteps, as shown in Figure 57.

Table 35. Absolute and Differential Spacecraft Potentials after 300 seconds for the "GeoCharging" Example

	Chassis	Kapton	OSR	Solar Cells	Teflon	Non-cond. Paint
Absolute Potential (kV)	-4	-4.0 to -5.3	-3.7 to -5.0	-2.4 to -3.7	-3.5 to -5.2	-4.4 to -5.3
Differential Potential (kV) ($V_{ins} – V_{cond}$)		-0.03 to -1.4	0.3 to -1.2	1.7 to 0.3	0.6 to -1.3	-0.4 to -1.4



Surface Element Groups

Plot	Condu...	Material	Norma...	X	Y	Z	Sunlit
□	Any	Black ...	180.0	0.0	0.0	0.0	Sunlit
□	Any	Graphi...	180.0	0.0	0.0	0.0	Dark
□	Any	Kapton	180.0	0.0	0.0	0.0	Any
☑	Any	NPaint	180.0	0.0	0.0	0.0	Any
□	Any	OSR	180.0	0.0	0.0	0.0	Any
□	Any	Solar ...	180.0	0.0	0.0	0.0	Any
□	Any	Teflon	180.0	0.0	0.0	0.0	Any

Individual Surface Elements

Plot	Element	Conductor	Material	Potential (V)
☑	31	1	Graphite	-3971.
☑	85	1	OSR	-4498.

Conductors

Plot	Conductor	Potential (V)
☑	1	-3971.

```
TimeSteps, Max3, Avg3, Min3, Element #31, Element #85, Condu
0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0
0.100, 5.855, 5.279, 5.195, 5.864, 5.839, 5.864
0.214, 0.465, -1.589, -1.895, -9.758E-2, -0.967, -9.758E-2
0.345, 0.805, -2.469, -2.954, -0.281, -1.638, -0.281
0.495, -0.133, -4.255, -4.877, -1.202, -3.004, -1.202
0.667, -2.258, -6.807, -7.498, -2.677, -5.152, -2.677
0.863, -4.992, -10.11, -10.88, -4.745, -7.906, -4.745
1.088, -8.382, -14.07, -14.91, -7.279, -11.54, -7.279
1.345, -13.44, -19.94, -20.89, -11.55, -16.16, -11.55
1.640, -22.40, -30.13, -31.25, -19.96, -26.64, -19.96
1.977, -42.51, -52.26, -53.70, -40.18, -46.94, -40.18
2.362, -57.38, -69.79, -71.62, -55.56, -65.17, -55.56
2.804, -68.62, -83.42, -85.56, -66.58, -76.29, -66.58
3.309, -83.97, -100.8, -103.2, -80.92, -93.79, -80.92
3.887, -101.7, -121.6, -124.5, -98.37, -111.4, -98.37
4.549, -122.6, -145.5, -148.8, -118.4, -136.4, -118.4
5.307, -145.4, -172.0, -175.9, -140.6, -158.7, -140.6
6.174, -172.0, -202.7, -207.2, -166.2, -190.2, -166.2
7.166, -201.2, -237.4, -242.6, -195.3, -219.5, -195.3
8.301, -235.9, -276.5, -282.5, -227.9, -260.2, -227.9
9.601, -273.5, -320.5, -327.3, -264.4, -296.9, -264.4
11.09, -316.7, -370.7, -378.6, -306.3, -349.6, -306.3
12.79, -366.5, -428.3, -437.3, -354.3, -397.8, -354.3
14.74, -419.1, -490.6, -501.0, -405.9, -463.5, -405.9
16.97, -483.2, -562.5, -574.2, -465.4, -523.1, -465.4
19.52, -553.1, -644.2, -657.6, -533.3, -591.2, -533.3
22.44, -631.3, -735.6, -750.8, -609.0, -687.7, -609.0
25.79, -720.0, -838.8, -856.2, -694.6, -773.3, -694.6
29.61, -818.4, -953.2, -972.9, -789.1, -893.7, -789.1
33.99, -928.6, -1082., -1104., -895.5, -999.8, -895.5
```

Figure 56. Results Tab Showing Text Subtab with Tabulated Results

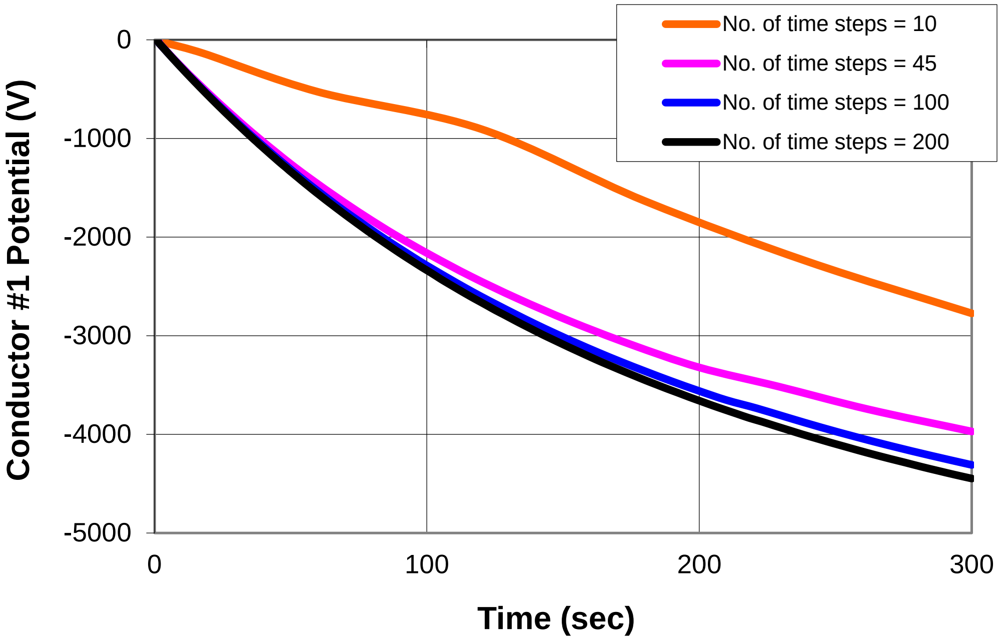
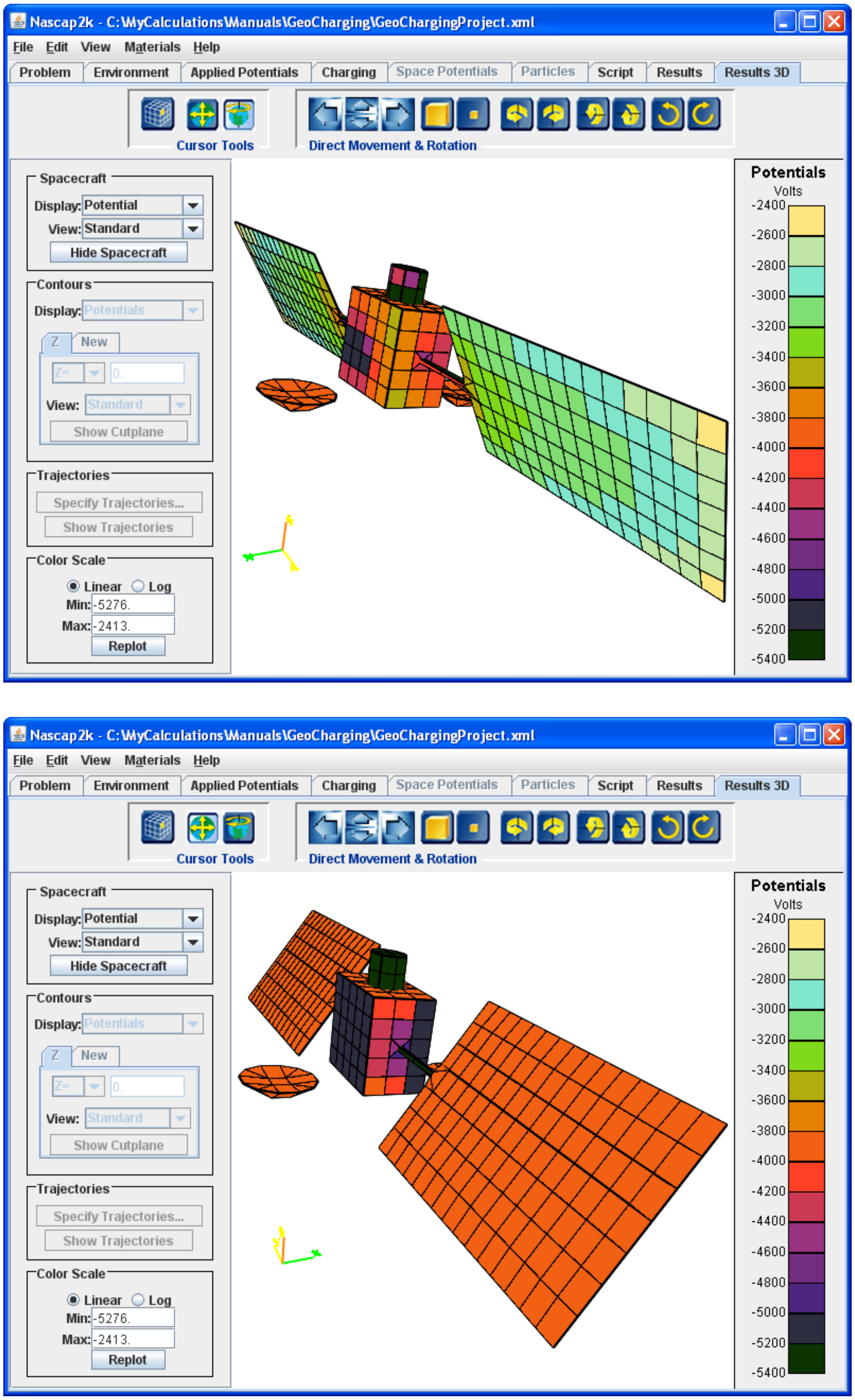


Figure 57. Sensitivity of Results on Choice of Number of Timesteps in the Charging Calculation of Case 1 of the “GeoCharging” Example

The **Results 3D** tab (Figure 58) shows potentials on the spacecraft from two different views. Notice that the least negative surface elements are at the end of the solar arrays while the most negative are the shaded boom (Kapton) and Teflon surface elements. Note in particular the high negative potential on the portion of the sun-facing face of the spacecraft that is shadowed by the antenna. Click the element selection tool (leftmost of the Cursor Tools) and click on one of these shadowed cells to verify that it is indeed shadowed.



Display: Potential
View: Standard

Display: Potentials
Z= 0.
View: Standard

● Linear ○ Log
Min: -5276.
Max: -2413.

Display: Potential
View: Standard

Display: Potentials
Z= 0.
View: Standard

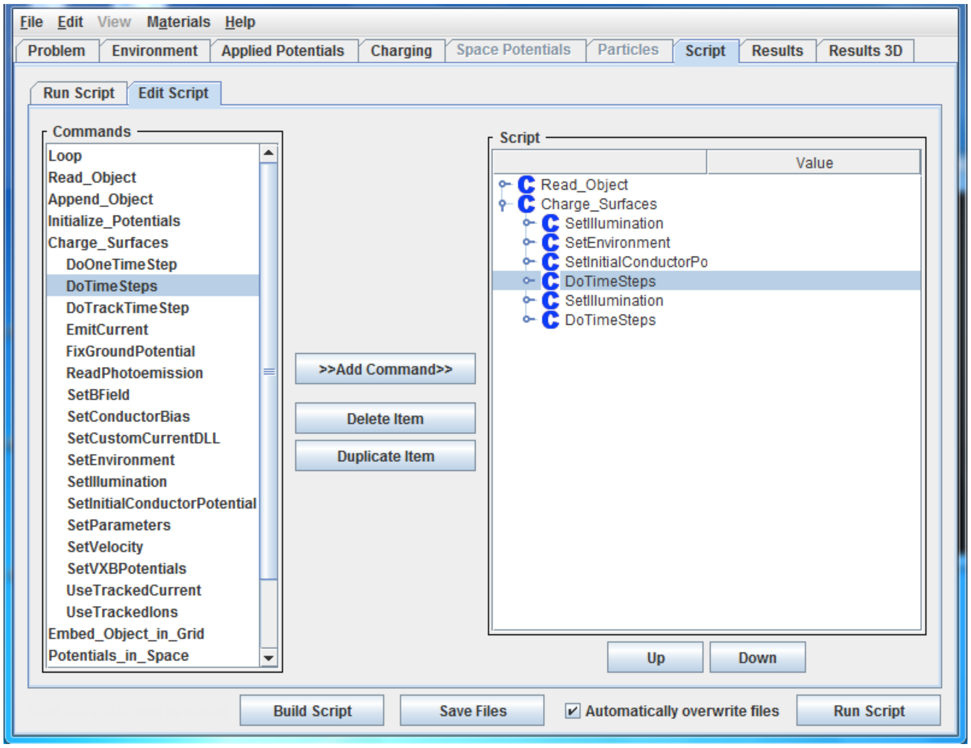
● Linear ○ Log
Min: -5276.
Max: -2413.

Figure 58. Results 3D Tab for Case 1 of "GeoCharging" Showing Spacecraft Potentials of Sunlit (Top) and Dark (Bottom) Surface Elements

18.3.2 Case 2: Eclipse Exit

The night-to-dawn transition is a likely region for surface charging-induced anomalies onboard the spacecraft. While in eclipse, the spacecraft may charge negatively to tens of kilovolts. A potential sufficient for discharge is easily created when the satellite emerges into sunlight, which results in near zero surface potentials due to photoelectron emission. In this example we perform an eclipse/sunlight charging calculation. We will calculate potentials at the end of five minutes of eclipse to obtain initial conditions for a five minute sunlight calculation. To preserve the earlier calculation, exit the code, make a new directory for the new case, copy all the files into the new directory, and restart the code, opening the copied project in the new directory.

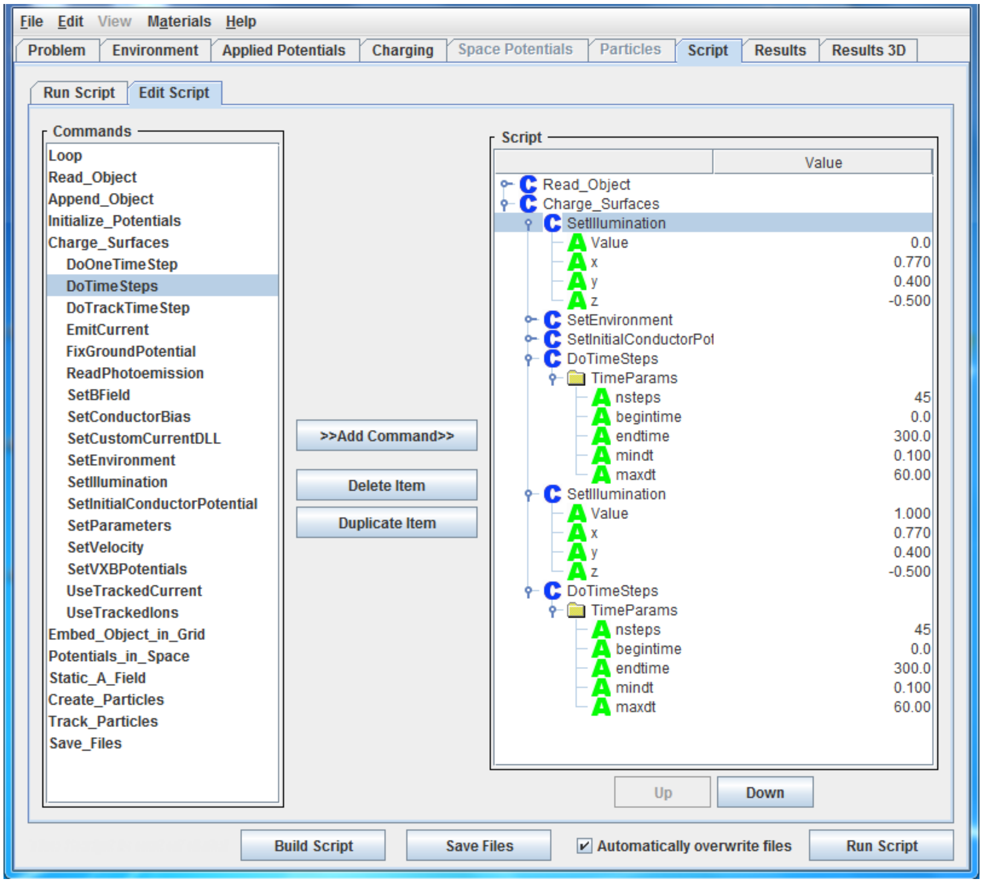
To perform the consecutive eclipse-sunlit calculation we must edit the script from the **Edit Script** subtab (Figure 59). We begin with the script of Case 1 and repeat the “SetIllumination” and “DoTimeSteps” commands immediately following the original “DoTimeSteps” command, as shown in Figure 59. To duplicate a command, select it and then click the “Duplicate Item” button. Use the “Up” and “Down” buttons to reorder commands. Set the illumination value to zero (0) the first time and one (1) the second time, as shown in Figure 60. Make sure the nsteps value of each “DoTimeSteps” command is set to 45. All other parameters remain as defined in Case 1. (Note that several such steps with varying illumination values could be used to exit eclipse at a finite rate.)



```
Read_Object
Charge_Surfaces
    SetIllumination
    SetEnvironment
    SetInitialConductorPo
    DoTimeSteps
    SetIllumination
    DoTimeSteps
```

☑ Automatically overwrite files

Figure 59. Edit Script Subtab for Case 2 of the “GeoCharging” Example

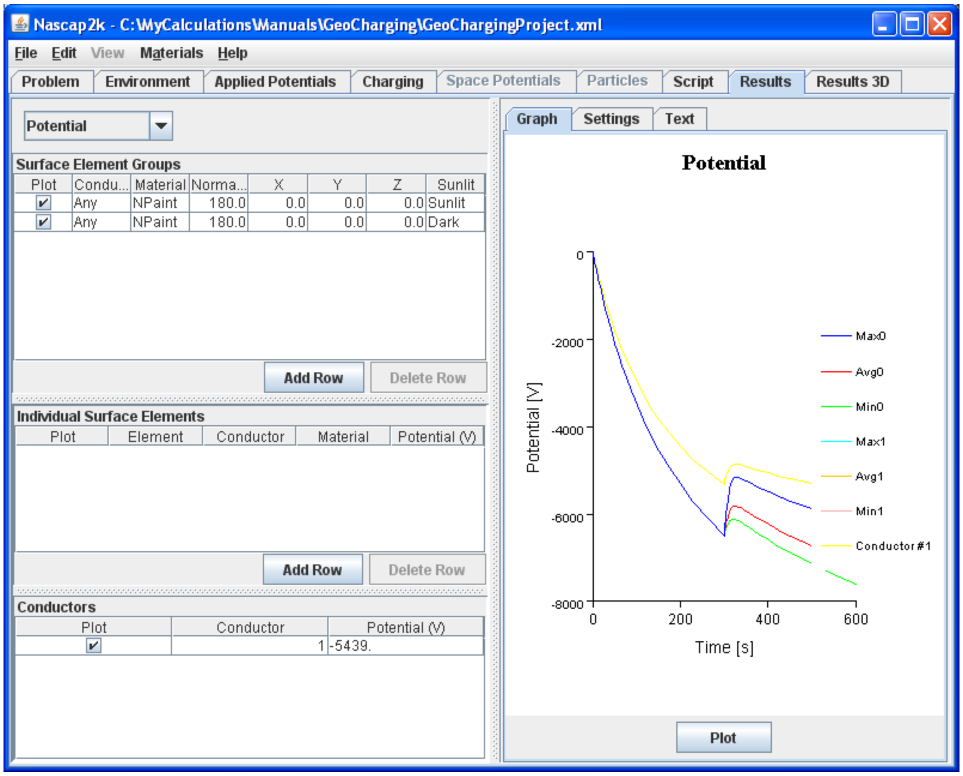


```
                                         Value
Read_Object
Charge_Surfaces
   SetIllumination
      Value                                0.0
      x                                  0.770
      y                                  0.400
      z                                 -0.500
   SetEnvironment
   SetInitialConductorPot
   DoTimeSteps
      TimeParams
         nsteps                             45
         begintime                         0.0
         endtime                         300.0
         mindt                           0.100
         maxdt                           60.00
   SetIllumination
      Value                              1.000
      x                                  0.770
      y                                  0.400
      z                                 -0.500
   DoTimeSteps
      TimeParams
         nsteps                             45
         begintime                         0.0
         endtime                         300.0
         mindt                           0.100
         maxdt                           60.00
```

☑ Automatically overwrite files

Figure 60. Expanded Script for Case 2 of the "GeoCharging" Example

Once the script is edited, it is executed by clicking the "Run Script" button. The **Results** tab (Figure 61) shows the history of the potential for various surface elements during the 10-minute time interval. The two time periods, before and after the eclipse exit, can be seen clearly from the Potential versus Time plots. During the eclipse period all the NPaint charges to equally negative differential potential with respect to the conductor. After a uniform increase in potential at eclipse exit, differential potentials develop among the sunlit NPaint cells. The dark NPaint cells (along with the shadowed sun-facing NPaint cells) continue to charge negative together.



Potential

Surface Element Groups

Plot	Condu...	Material	Norma...	X	Y	Z	Sunlit
☑	Any	NPaint	180.0	0.0	0.0	0.0	Sunlit
☑	Any	NPaint	180.0	0.0	0.0	0.0	Dark

Individual Surface Elements

Plot	Element	Conductor	Material	Potential (V)

Conductors

Plot	Conductor	Potential (V)
☑	1	-5439.

Figure 61. Results Tab for Case 2 of the "GeoCharging" Example

19 Current Collection in a Low-Earth-Orbit Plasma (example name: "Bipolar")

19.1 Background

A common issue on low Earth orbit spacecraft is the prediction and control of interactions between a spacecraft with high-voltage components (ranging from a few volts to kilovolts) and the ionospheric environment. Ever since electron guns were first placed on rockets, the voltage on the main body necessary to collect ionospheric electrons and complete the circuit has been the subject of numerous theoretical and experimental studies. A large-scale effort to address such issues was the SPEAR series of experiments. SPEAR-I[2] was designed to measure whether Earth's magnetic field impedes electron collection, SPEAR-II was designed to test pulsed high-voltage components, and SPEAR-III[3] was designed to test proposed spacecraft grounding mechanisms. The following example illustrates the implementation of *Nascap-2k* to study the physics associated with current collection by the bipolar plasma sheath generated by a SPEAR-I/SPEAR-III like object.

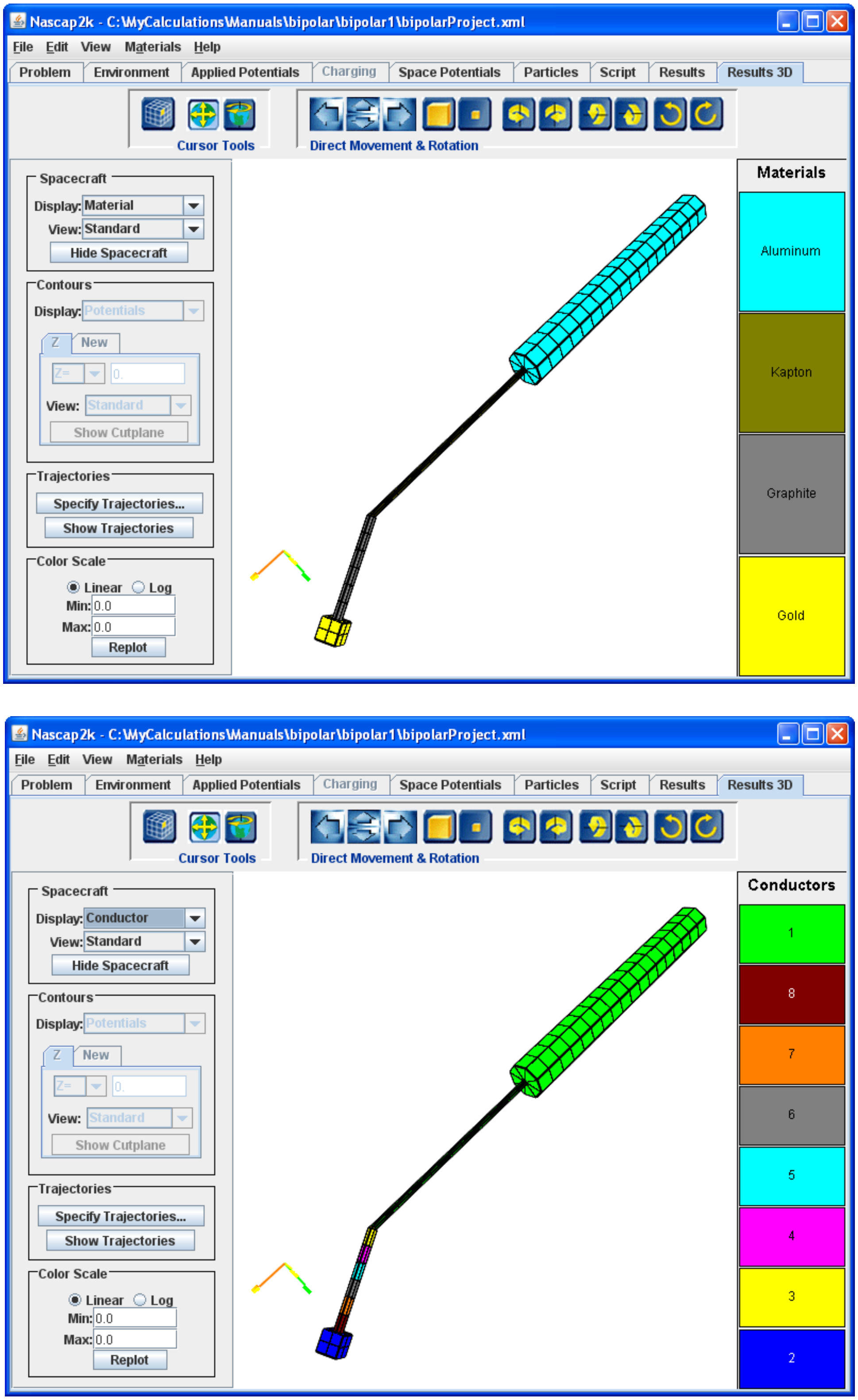
In the following example, a new problem—Bipolar—should be created, and the object "Bipolar" should be loaded from the **Nascap2k_4/Manual/Example Problems/Bipolar** folder (BipolarObject.xml).

19.2 Object and Grid Definition

The object (constructed using *Object Toolkit*) is shown in Figure 62. It consists of a gold-plated cube (Figure 63) mounted on a cylindrical boom (Figure 64). The boom is connected to a cylindrical support boom covered with an insulator (Figure 65). This boom is in turn connected to the main (aluminum) rocket body (Figure 66). In SPEAR-I and SPEAR-III this part of the rocket was a bushing constructed with graded rings that were connected by resistors. The graded boom created a uniform potential gradient from the positively biased cube to payload ground.

The grid surrounding the object is constructed using *GridTool*. The example involves calculating both electron-collecting (surrounding the cube) and ion-collecting (main body) sheaths that have different characteristic scale lengths. Therefore, to resolve the space potentials accurately it is necessary to incorporate six grids of different extents and resolution based on the region of space in which the potentials are to be computed. The specifications of all the grids are shown in Figure 67. The combined grid arrangement with the object embedded is shown in Figure 68.

To build the problem grid, click “Edit Grid” on the **Problem** tab. This launches *GridTool*. On *GridTool*’s **File** menu, select “Import Object” and import the “Bipolar” object. Under the **Grid** menu, select “New Primary Grid,” and set the grid dimensions and mesh size to those shown in the top left dialog box in Figure 67. Click the primary grid folder icon to the right of the 3-D object/grid display, and select “New Child Grid” on the **Grid** menu, setting the limits and subdivision ratio as shown in the **Child Grid** dialog box for grid number 2 in the top right dialog box of Figure 67. Make grids 3 and 4 the “children” of grid 2, and make grids 5 and 6 the children of grid 3, setting the dimensions as shown. Save the grid to the current project by selecting “Save Grid” from the *GridTool*’s **File** menu.


Nascap2k - C:\MyCalculations\Manuals\bipolar\bipolar1\bipolarProject.xml
File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D
Cursor Tools
Direct Movement & Rotation
Hide Spacecraft
Show Cutplane
Specify Trajectories...
Show Trajectories
Replot

Spacecraft
Display: Material
View: Standard

Contours
Display: Potentials
View: Standard

Color Scale
● Linear ○ Log
Min: 0.0
Max: 0.0

Materials

Materials
Aluminum
Kapton
Graphite
Gold

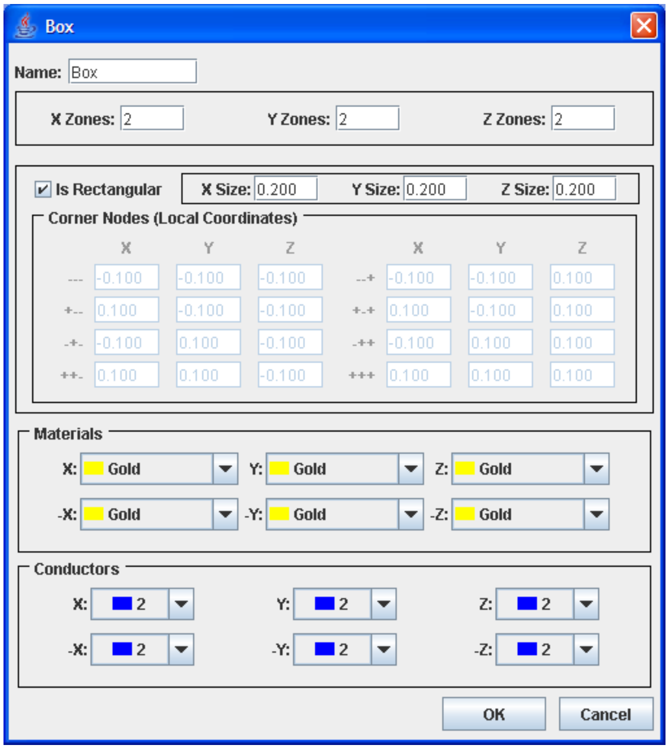
Spacecraft
Display: Conductor
View: Standard

Contours
Display: Potentials
View: Standard

Color Scale
● Linear ○ Log
Min: 0.0
Max: 0.0

Conductors
1
8
7
6
5
4
3
2

Figure 62. Object Constructed for the Study of Current Collection from a Bipolar Sheath in a Low-Earth-Orbit Environment. Top: Object Materials. Bottom: Object Conductors



Box

Name: Box

X Zones: 2 Y Zones: 2 Z Zones: 2

☑ Is Rectangular X Size: 0.200 Y Size: 0.200 Z Size: 0.200

Corner Nodes (Local Coordinates)

	X	Y	Z		X	Y	Z
---	-0.100	-0.100	-0.100	--+	-0.100	-0.100	0.100
+--	0.100	-0.100	-0.100	+-+	0.100	-0.100	0.100
-+-	-0.100	0.100	-0.100	-++	-0.100	0.100	0.100
++-	0.100	0.100	-0.100	+++	0.100	0.100	0.100

Materials

X: 🟨 Gold Y: 🟨 Gold Z: 🟨 Gold

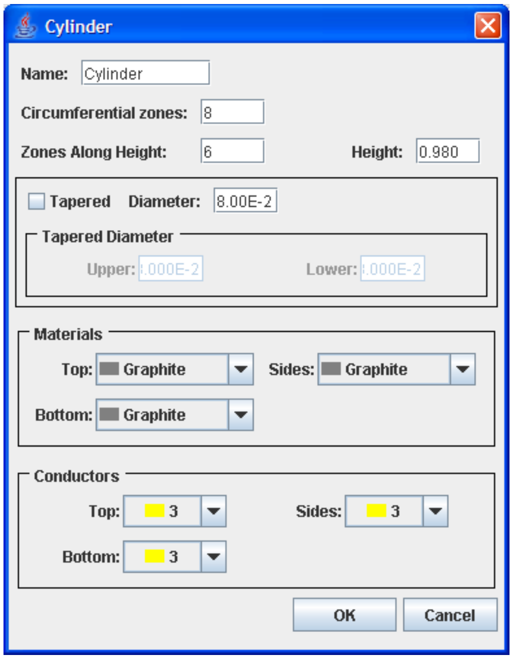
-X: 🟨 Gold -Y: 🟨 Gold -Z: 🟨 Gold

Conductors

X: 🟦 2 Y: 🟦 2 Z: 🟦 2

-X: 🟦 2 -Y: 🟦 2 -Z: 🟦 2

Figure 63. Specifications of Gold-plated Cube in Figure 62



Cylinder

Name: Cylinder

Circumferential zones: 8

Zones Along Height: 6 Height: 0.980

☐ Tapered Diameter: 8.00E-2

Tapered Diameter

Upper: .000E-2 Lower: .000E-2

Materials

Top: ▨ Graphite Sides: ▨ Graphite

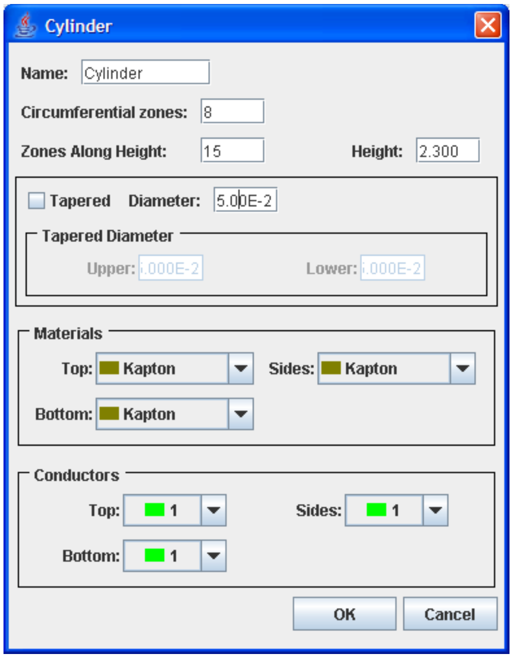
Bottom: ▨ Graphite

Conductors

Top: 🟨 3 Sides: 🟨 3

Bottom: 🟨 3

Figure 64. Specifications of Graded Boom in Figure 62



Name: Cylinder

Circumferential zones: 8

Zones Along Height: 15 Height: 2.300

☐ Tapered Diameter: 5.00E-2

Tapered Diameter

Upper: ,000E-2 Lower: ,000E-2

Materials

Top: Kapton Sides: Kapton

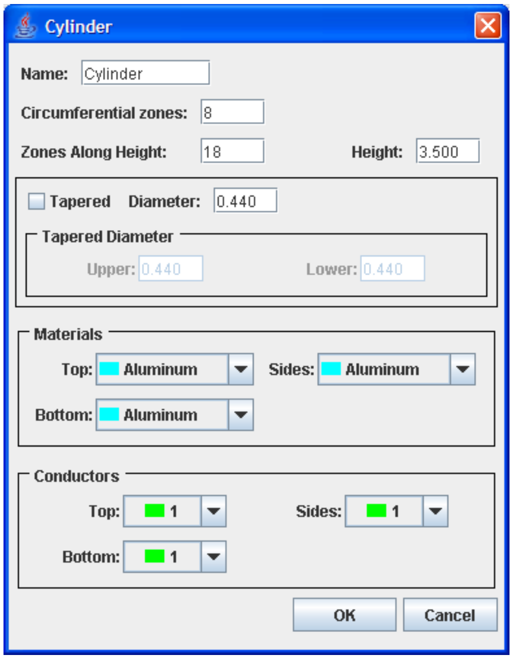
Bottom: Kapton

Conductors

Top: 1 Sides: 1

Bottom: 1

Figure 65. Specifications of Kapton Support Boom in Figure 62



Name: Cylinder

Circumferential zones: 8

Zones Along Height: 18 Height: 3.500

☐ Tapered Diameter: 0.440

Tapered Diameter

Upper: 0.440 Lower: 0.440

Materials

Top: Aluminum Sides: Aluminum

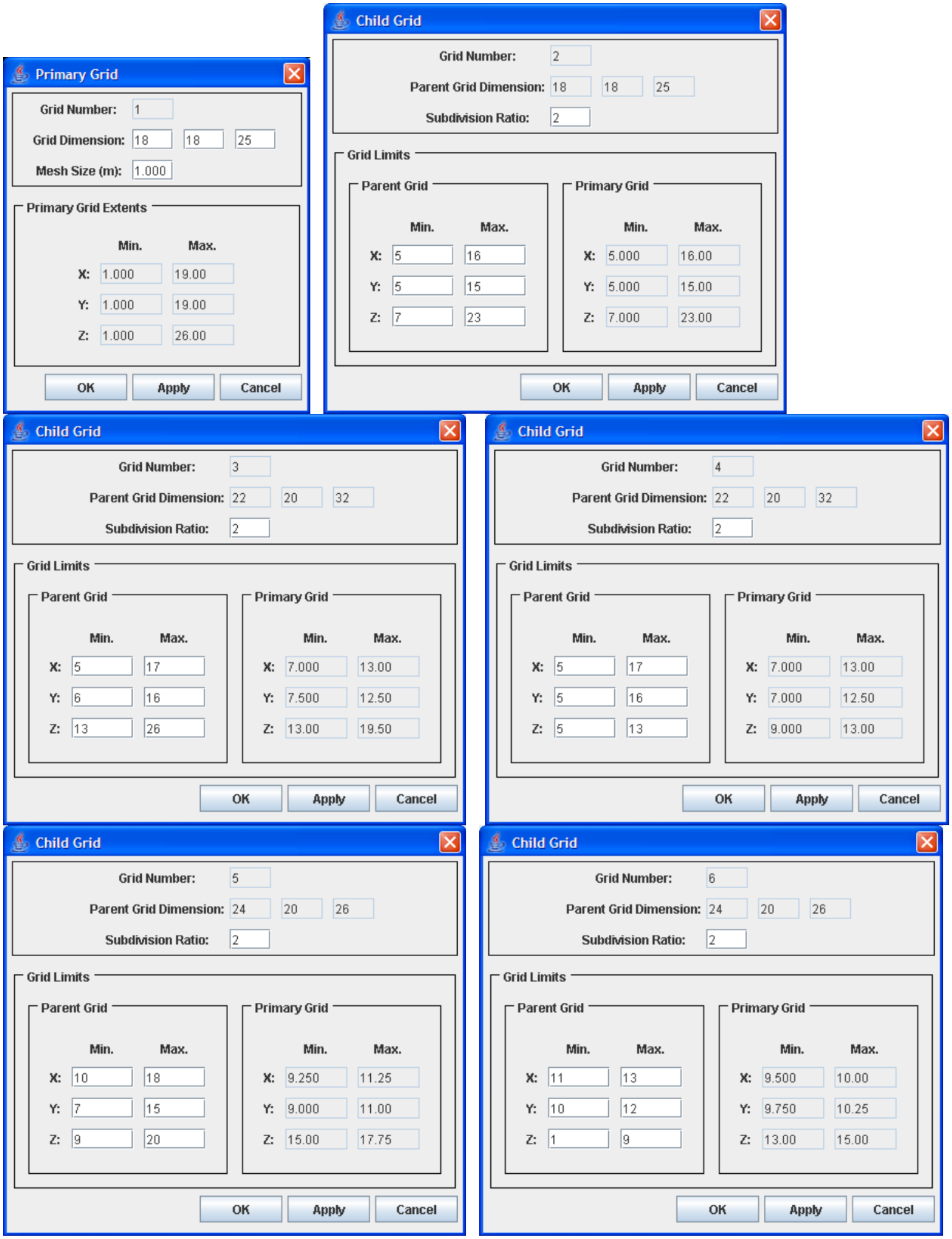
Bottom: Aluminum

Conductors

Top: 1 Sides: 1

Bottom: 1

Figure 66. Specifications of Main Rocket Body in Figure 62



Grid Number: 1

Grid Dimension: 18 18 25

Mesh Size (m): 1.000

Primary Grid Extents

	Min.	Max.
X:	1.000	19.00
Y:	1.000	19.00
Z:	1.000	26.00

Grid Number: 2

Parent Grid Dimension: 18 18 25

Subdivision Ratio: 2

Grid Limits

	Parent Grid		Primary Grid	
	Min.	Max.	Min.	Max.
X:	5	16	5.000	16.00
Y:	5	15	5.000	15.00
Z:	7	23	7.000	23.00

Grid Number: 3

Parent Grid Dimension: 22 20 32

Subdivision Ratio: 2

Grid Limits

	Parent Grid		Primary Grid	
	Min.	Max.	Min.	Max.
X:	5	17	7.000	13.00
Y:	6	16	7.500	12.50
Z:	13	26	13.00	19.50

Grid Number: 4

Parent Grid Dimension: 22 20 32

Subdivision Ratio: 2

Grid Limits

	Parent Grid		Primary Grid	
	Min.	Max.	Min.	Max.
X:	5	17	7.000	13.00
Y:	5	16	7.000	12.50
Z:	5	13	9.000	13.00

Grid Number: 5

Parent Grid Dimension: 24 20 26

Subdivision Ratio: 2

Grid Limits

	Parent Grid		Primary Grid	
	Min.	Max.	Min.	Max.
X:	10	18	9.250	11.25
Y:	7	15	9.000	11.00
Z:	9	20	15.00	17.75

Grid Number: 6

Parent Grid Dimension: 24 20 26

Subdivision Ratio: 2

Grid Limits

	Parent Grid		Primary Grid	
	Min.	Max.	Min.	Max.
X:	11	13	9.500	10.00
Y:	10	12	9.750	10.25
Z:	1	9	13.00	15.00

Figure 67. Grid Specifications for the Parent and Child Grids Used in the “Bipolar” Example

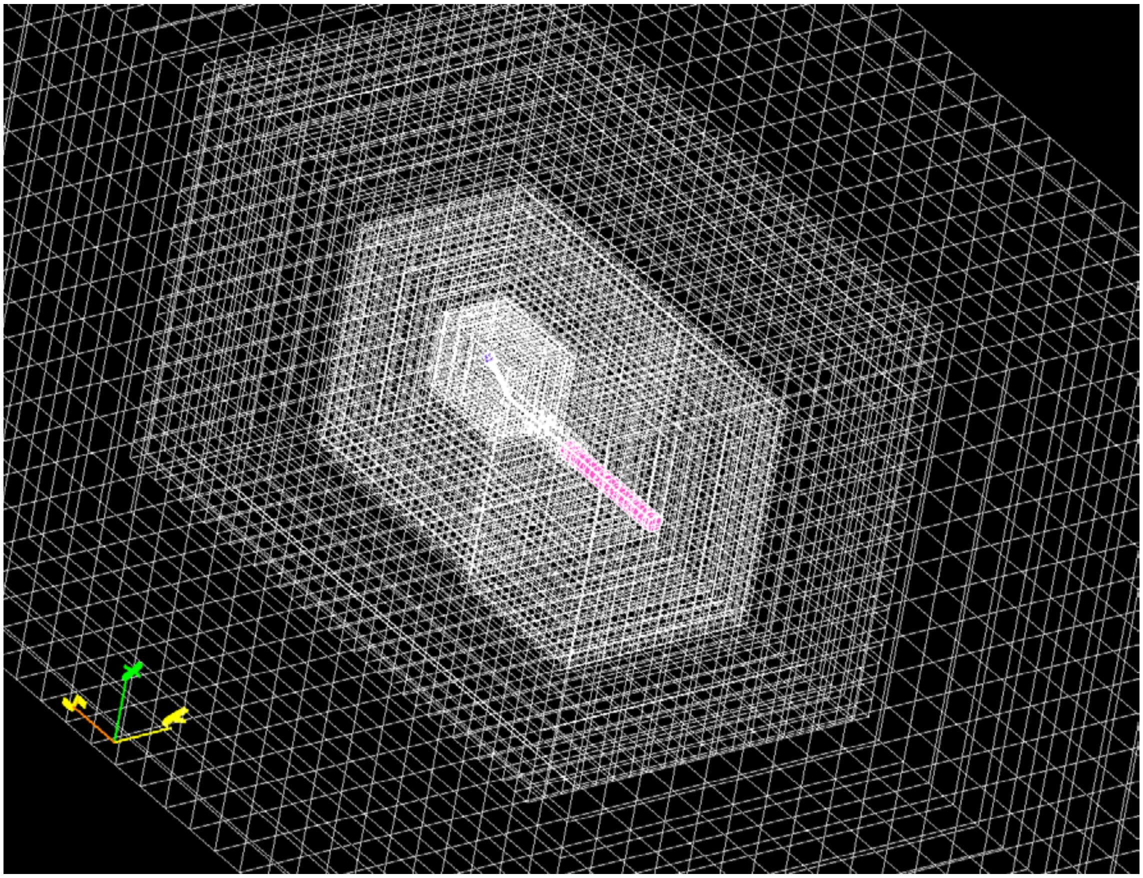
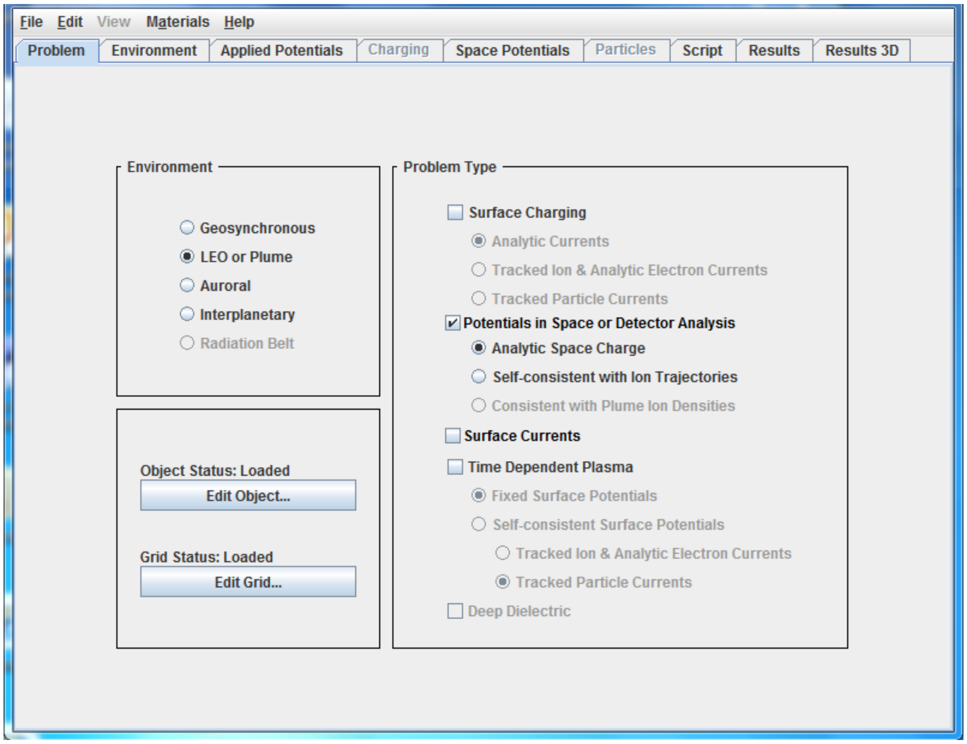


Figure 68. Grid Arrangement Showing All Six Grid Levels and Embedded Object for the “Bipolar” Example

19.3 Case 1: Electron Collection

19.3.1 Potentials in Space Calculation

Figure 69 shows the **Problem** tab with “LEO” checked under “Environment” and “Potentials in Space” checked under “Problem Type.” This calculation consists of computing potentials in a low Earth orbit environment. We later compute the current collected. We use an analytic space charge model in this example. The object and grid must be loaded before these choices are available on the user interface. The object is loaded using the “Load Object” choice on the **File** menu. If a grid file with the appropriate name is present, the grid is automatically loaded on code start-up and on return from *GridTool*. If the grid is not loaded, open the grid file (and the object file) in *GridTool* and save the grid to the same directory as the rest of the project files.



Environment

○ Geosynchronous
● LEO or Plume
○ Auroral
○ Interplanetary
○ Radiation Belt

Object Status: Loaded

Grid Status: Loaded

Problem Type

□ Surface Charging
- ● Analytic Currents
- ○ Tracked Ion & Analytic Electron Currents
- ○ Tracked Particle Currents

☑ Potentials in Space or Detector Analysis
- ● Analytic Space Charge
- ○ Self-consistent with Ion Trajectories
- ○ Consistent with Plume Ion Densities

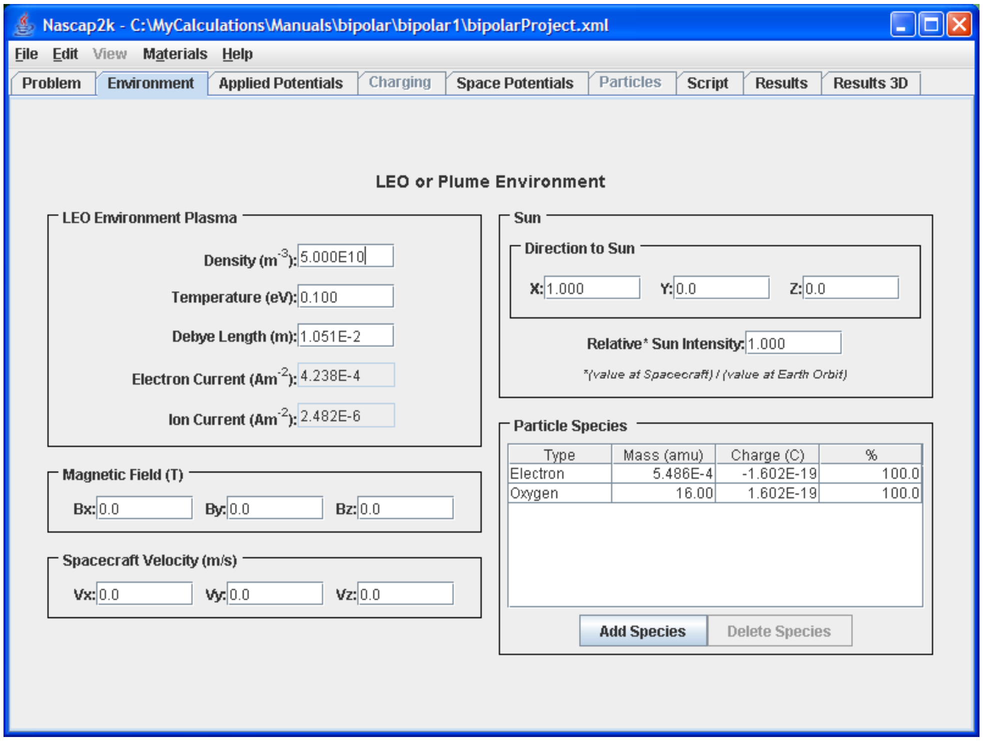
□ Surface Currents

□ Time Dependent Plasma
- ● Fixed Surface Potentials
- ○ Self-consistent Surface Potentials
  - ○ Tracked Ion & Analytic Electron Currents
  - ● Tracked Particle Currents

□ Deep Dielectric

Figure 69. Problem Tab for the “Bipolar” Example

The **Environment** tab is shown in Figure 70. The plasma density we use, 5 x 10^{10} m^{-3}, is considerably lower than the default value (10^{12} m^{-3}). We assume 100% oxygen ions by clicking the “Add Species” button and changing the name “Unknown” to “Oxygen” (the mass, charge, and percentage are already correct). We begin with no magnetic field; all other environment parameters remain unchanged for these calculations.



LEO or Plume Environment

LEO Environment Plasma

Density (m^{-3}): 5.000E10

Temperature (eV): 0.100

Debye Length (m): 1.051E-2

Electron Current (Am^{-2}): 4.238E-4

Ion Current (Am^{-2}): 2.482E-6

Magnetic Field (T)

Bx: 0.0 By: 0.0 Bz: 0.0

Spacecraft Velocity (m/s)

Vx: 0.0 Vy: 0.0 Vz: 0.0

Sun

Direction to Sun

X: 1.000 Y: 0.0 Z: 0.0

Relative* Sun Intensity: 1.000

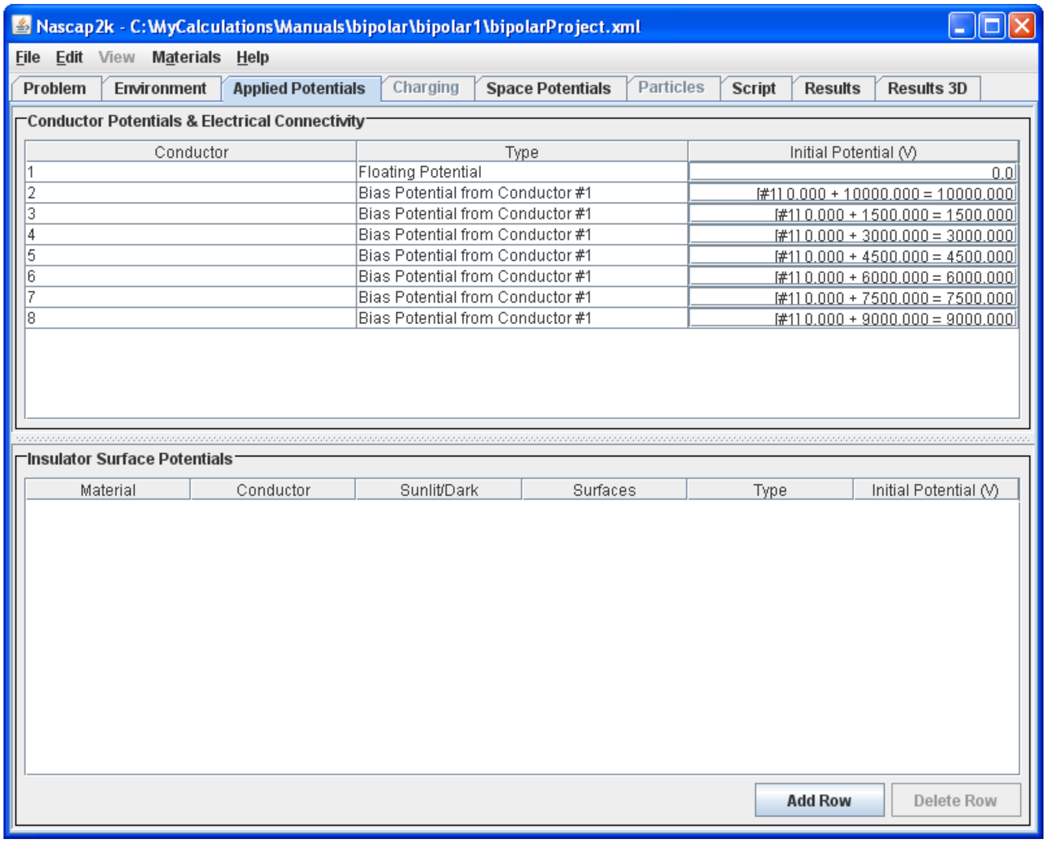
*(value at Spacecraft) / (value at Earth Orbit)

Particle Species

Type	Mass (amu)	Charge (C)	%
Electron	5.486E-4	-1.602E-19	100.0
Oxygen	16.00	1.602E-19	100.0

Figure 70. Environment Tab for the “Bipolar” Example, for Case 1 and Zero Ambient Magnetic Field

In Case 1, the main body is held at ground potential. The conductor potentials are set as shown on the **Applied Potentials** tab (Figure 71). The gold-plated cube is biased to +10 kV with respect to the body, and each of the remaining six conductors is biased positively in 1.5 kV increments. Set the type from the drop-down menu, and enter the initial or bias potential by double clicking in the “Initial Potential” box and entering the appropriate value.

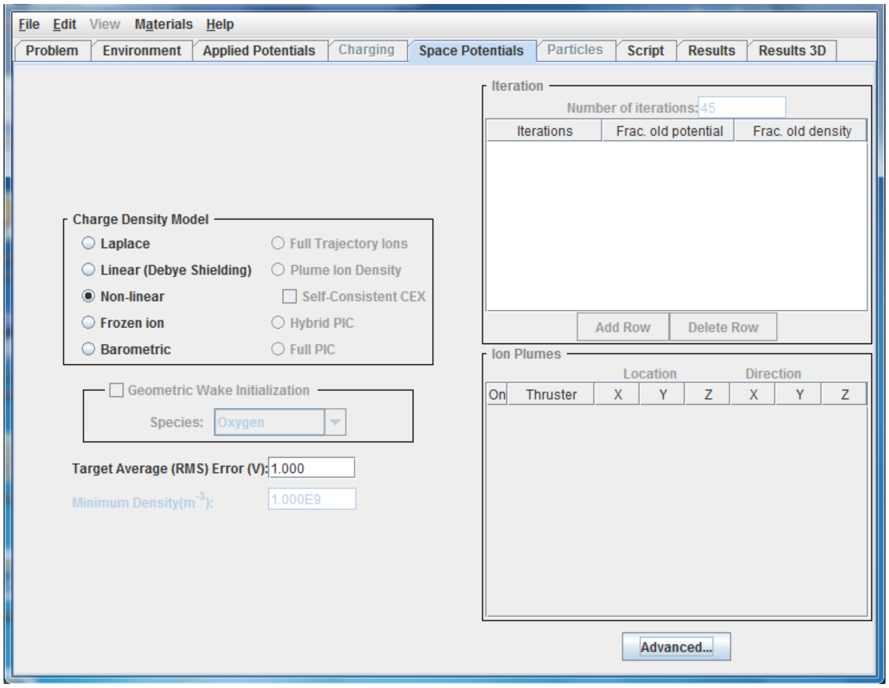

Nascap2k - C:\MyCalculations\Manuals\bipolar\bipolar1\bipolarProject.xml
File
Edit
View
Materials
Help
Problem
Environment
Applied Potentials
Charging
Space Potentials
Particles
Script
Results
Results 3D
Conductor Potentials & Electrical Connectivity
Insulator Surface Potentials
Add Row
Delete Row

Conductor	Type	Initial Potential (V)
1	Floating Potential	0.0
2	Bias Potential from Conductor #1	[#1] 0.000 + 10000.000 = 10000.000
3	Bias Potential from Conductor #1	[#1] 0.000 + 1500.000 = 1500.000
4	Bias Potential from Conductor #1	[#1] 0.000 + 3000.000 = 3000.000
5	Bias Potential from Conductor #1	[#1] 0.000 + 4500.000 = 4500.000
6	Bias Potential from Conductor #1	[#1] 0.000 + 6000.000 = 6000.000
7	Bias Potential from Conductor #1	[#1] 0.000 + 7500.000 = 7500.000
8	Bias Potential from Conductor #1	[#1] 0.000 + 9000.000 = 9000.000

Material	Conductor	Sunlit/Dark	Surfaces	Type	Initial Potential (V)

Figure 71. Applied Potentials Tab for Case 1 of the “Bipolar” Example

On the **Space Potentials** tab, select the “Non-linear” analytic space charge density model as it is appropriate for steady-state calculations in low Earth orbit plasmas and is used in this example for computing the potential distribution around the object. The model is described in greater detail in Section 14.1. Because an analytic space charge formulation is used, no iterations between potentials and particles are needed. Considering the kilovolt-level potentials associated with the object surfaces (Figure 72), the “Target Average (RMS) Error” is set to 1 V. The choices on the **Advanced Potential Solver Parameters** dialog box (Section 14.1) remain at their default values.



Iteration

Number of iterations: 45

Iterations	Frac. old potential	Frac. old density

Charge Density Model

○ Laplace
○ Linear (Debye Shielding)
● Non-linear
○ Frozen ion
○ Barometric
○ Full Trajectory Ions
○ Plume Ion Density
□ Self-Consistent CEX
○ Hybrid PIC
○ Full PIC

□ Geometric Wake Initialization

Species: Oxygen

Target Average (RMS) Error (V): 1.000

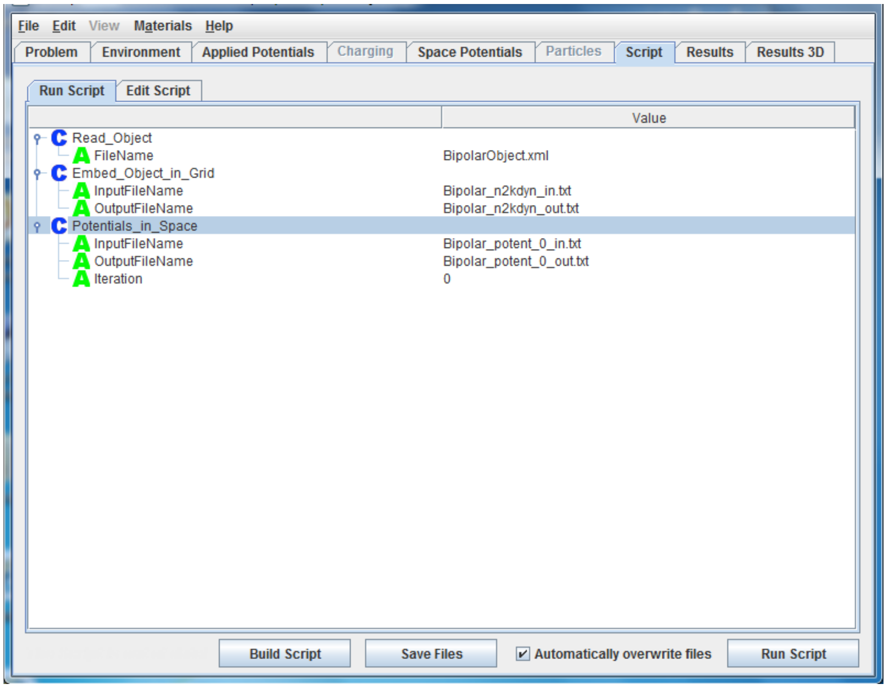
Minimum Density(m^{-3}): 1.000E9

Ion Plumes

		Location			Direction		
On	Thruster	X	Y	Z	X	Y	Z

Figure 72. Space Potentials Tab for the "Bipolar" Example

The actual execution of the calculation is launched from the **Script** tab (Figure 73). Initially, because no script has been generated, the *"Script is out of date!"* message appears. To build the script, click the "Build Script" button.



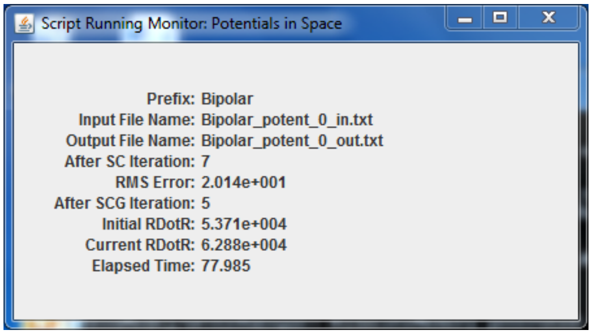
	Value
C Read_Object	
A FileName	BipolarObject.xml
C Embed_Object_in_Grid	
A InputFileName	Bipolar_n2kdyn_in.txt
A OutputFileName	Bipolar_n2kdyn_out.txt
C Potentials_in_Space	
A InputFileName	Bipolar_potent_0_in.txt
A OutputFileName	Bipolar_potent_0_out.txt
A Iteration	0

☑ Automatically overwrite files

Figure 73. Run Script Subtab Showing the List of Commands and Arguments for Case 1 of the "Bipolar" Example

Note the text files associated with the arguments for the **Potentials in Space** script element. These files contain input and output information associated with the **Potentials in Space** module and are written when either the “Run Script” or “Save Files” button is clicked.

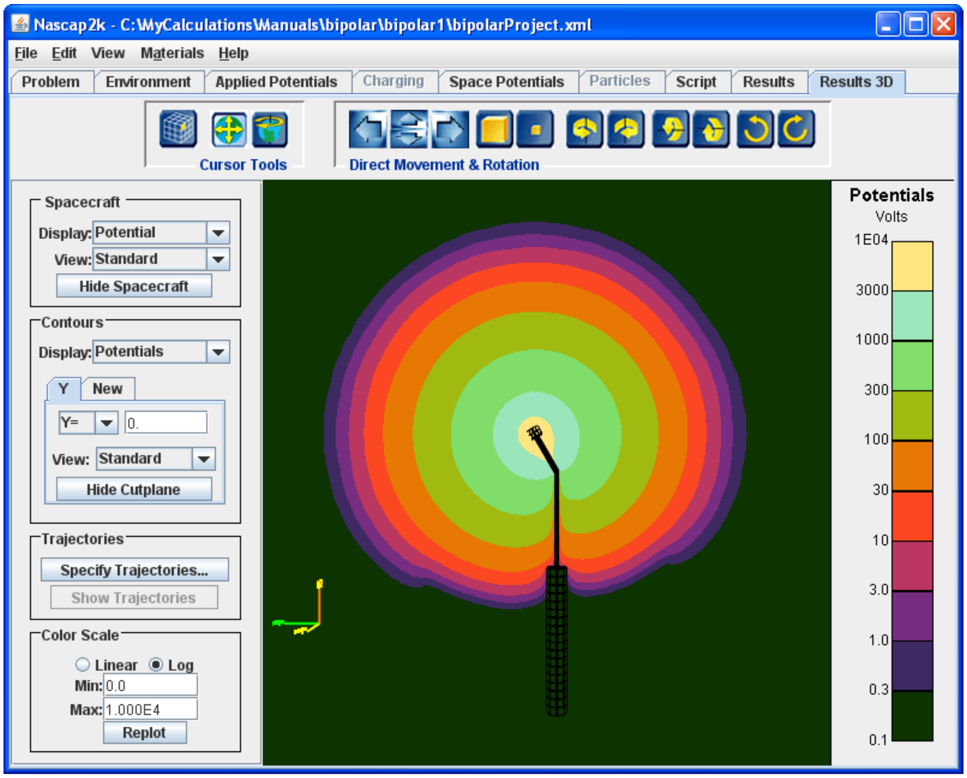
We are now ready to compute. Click the “Run Script” button to launch the calculation. The electric potential solution is monitored through the **Script Running Monitor**. Figure 74 shows progress on the 7th space charge (SC) iteration at which the RMS error is still 20.14 V. At the 20th iteration the value is 1.35 V, slightly more than the requested value of 1 V. (The slow convergence is related to the high screening in the low potential region into which the sheath is trying to expand.) This information is provided at the end of the **Potentials in Space** output file. (Search for the string “rmserr” in the **Bipolar_potent_0_out.txt file.**)



Prefix: Bipolar
Input File Name: Bipolar_potent_0_in.txt
Output File Name: Bipolar_potent_0_out.txt
After SC Iteration: 7
RMS Error: 2.014e+001
After SCG Iteration: 5
Initial RDotR: 5.371e+004
Current RDotR: 6.288e+004
Elapsed Time: 77.985

Figure 74. Script Running Monitor Showing Computational Diagnostics at the 10th Space Charge Calculation

Figure 75 shows a Y=0 cut plane of the results of the potential calculation for Case 1. To display (or hide) the cut plane, click on the “Show (Hide) Cut Plane” button. Note that we have selected a log color scale and changed the limits. The electron-collecting sheath surrounds the positively biased surface elements of the object while no ion-collecting sheath exists because no negatively biased components were defined. As a prelude to calculating current collection by the object, it is useful to view electron trajectories. Click the “Specify Trajectories” button on the **Results 3D** tab. The **Particle Visualization** dialog box appears. The parameters are chosen as shown in Figure 76. The minimum Z value of the tracking limits may need to be adjusted slightly to eliminate additional trajectories. Click the “OK” button to start the calculation. Note that the “Contour” option for the initial particle distribution was chosen (Section 15.1). This option requires a value for the desired contour value of the potential. We chose a value of 1.724 V, which, as is explained in the next section, is the sheath edge potential. The electron trajectories are shown in Figure 77. Note that we have turned off the cut plane. The **View** menu has options such as “Set Background Color” that can be used to tailor the view.



Spacecraft

Display: Potential

View: Standard

Contours

Display: Potentials

Y= 0.

View: Standard

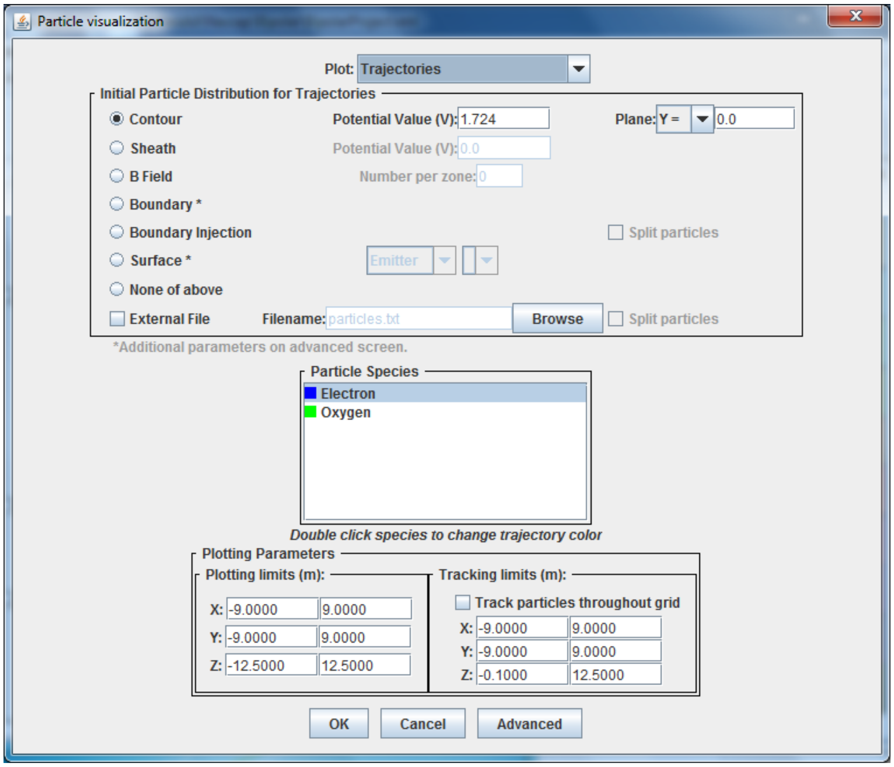
Color Scale

○ Linear ● Log

Min: 0.0

Max: 1.000E4

Figure 75. Distribution of the Electric Potential on a Y=0 Cut Plane for Case 1 of the “Bipolar” Example



Plot: Trajectories

Initial Particle Distribution for Trajectories

● Contour Potential Value (V): 1.724 Plane: Y = 0.0

○ Sheath Potential Value (V): 0.0

○ B Field Number per zone: 0

○ Boundary *

○ Boundary Injection □ Split particles

○ Surface * Emitter

○ None of above

□ External File Filename: particles.txt □ Split particles

*Additional parameters on advanced screen.

Particle Species

🟦 Electron

🟩 Oxygen

Plotting Parameters

Plotting limits (m):

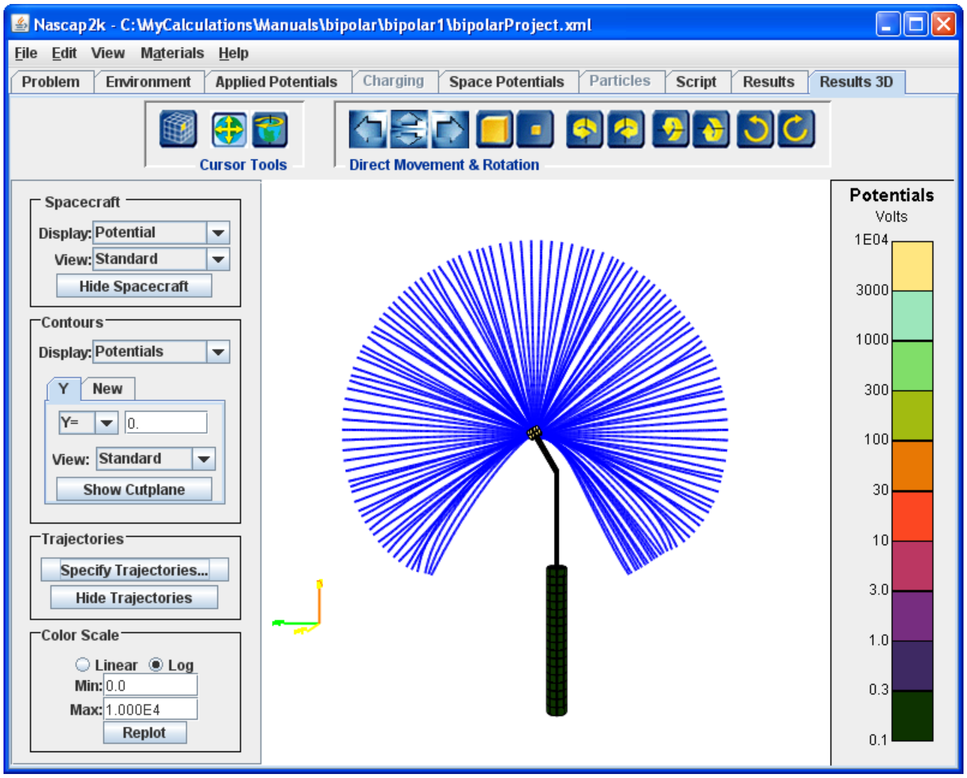
X:	-9.0000	9.0000
Y:	-9.0000	9.0000
Z:	-12.5000	12.5000

Tracking limits (m):

□ Track particles throughout grid

X:	-9.0000	9.0000
Y:	-9.0000	9.0000
Z:	-0.1000	12.5000

Figure 76. Particle Visualization Dialog Box for Case 1 of the “Bipolar” Example



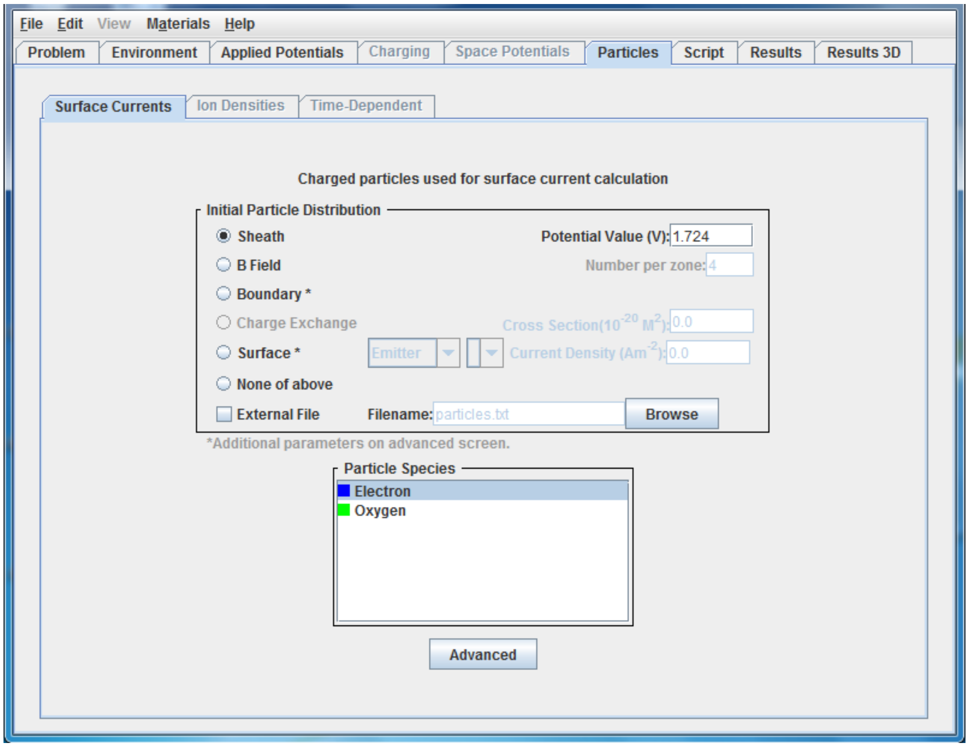
Display: Potential
View: Standard
Display: Potentials
Y= 0.
View: Standard
○ Linear ● Log
Min: 0.0
Max: 1.000E4

Figure 77. Electron Trajectories for Case 1 of the “Bipolar” Example

19.3.2 Surface Currents Calculation

In this part of the example, we compute current collection for zero and non-zero magnetic fields. Return to the **Problem** tab, uncheck “Potentials in Space,” and check “Surface Currents.”

Go to the **Surface Currents** subtab of the **Particles** tab as shown in Figure 78. Select the “Sheath” option (Section 15.1) and highlight “electron” in the “Particle Species” box to compute electron current collection. This option requires the value of the potential at the sheath boundary. To determine the appropriate value, use the potential contours figure on the **Results 3D** tab. Using appropriate color scale limits (Min=0 V, Max=10 V), Figure 79 shows that the sheath edge lies mostly in Grid #2. (Remember to click “Replot” when changing the plot.) The sheath boundary potentials for each grid are given in the **bipolar_potent_0_out.txt** file as shown in Figure 80. Using Figure 79 and Figure 80, we chose a value of 1.724 V as displayed in Figure 78.



Charged particles used for surface current calculation

Initial Particle Distribution

● Sheath Potential Value (V): 1.724

○ B Field Number per zone: 4

○ Boundary *

○ Charge Exchange Cross Section(10^{-20} M^2): 0.0

○ Surface * Emitter Current Density (Am^{-2}): 0.0

○ None of above

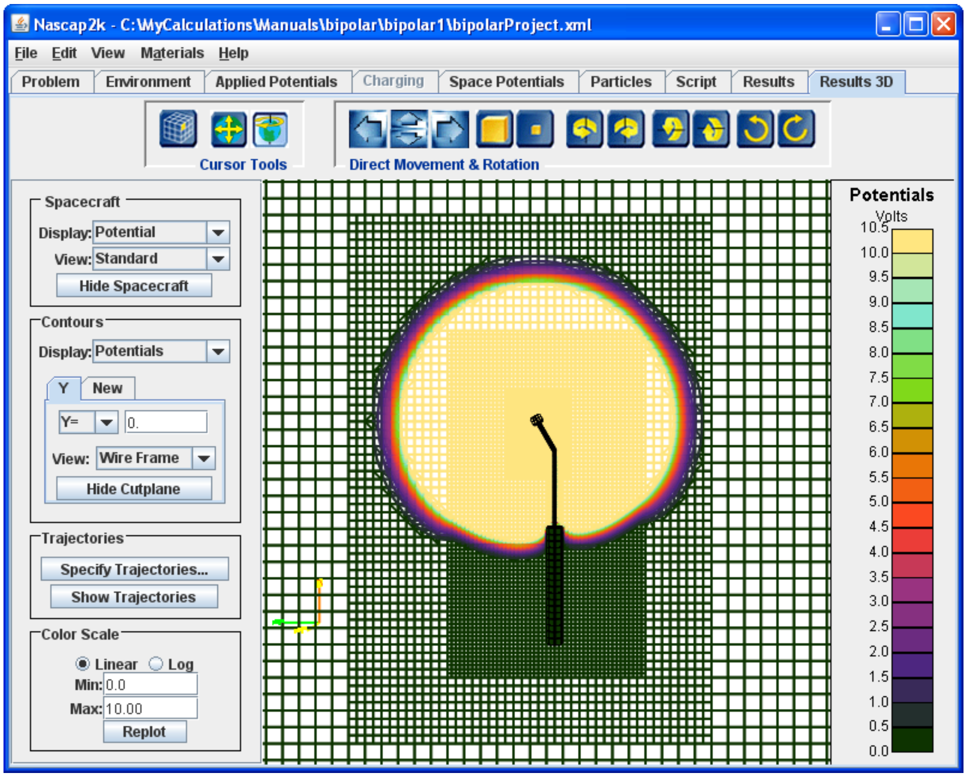
□ External File Filename: particles.txt

*Additional parameters on advanced screen.

Particle Species

🟦 Electron
🟩 Oxygen

Figure 78. Parameters on the Surface Currents Subtab Used to Compute the Electron Current Collection for the “Bipolar” Example



Spacecraft

Display: Potential

View: Standard

Contours

Display: Potentials

Y

Y= 0.

View: Wire Frame

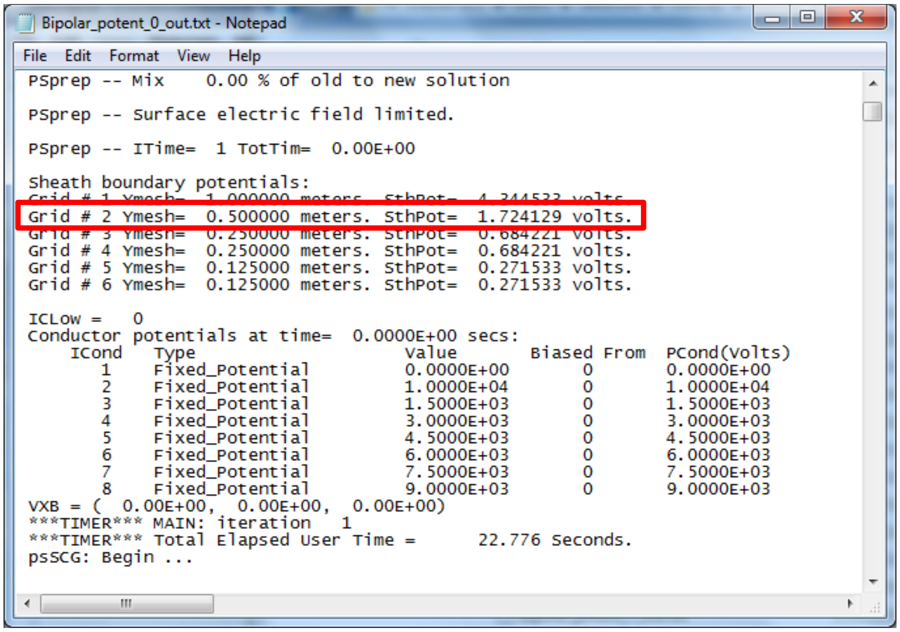
Color Scale

● Linear ○ Log

Min: 0.0

Max: 10.00

Figure 79. Potential Distribution Showing Sheath Edge on Mesh for Case 1 of the “Bipolar” Example

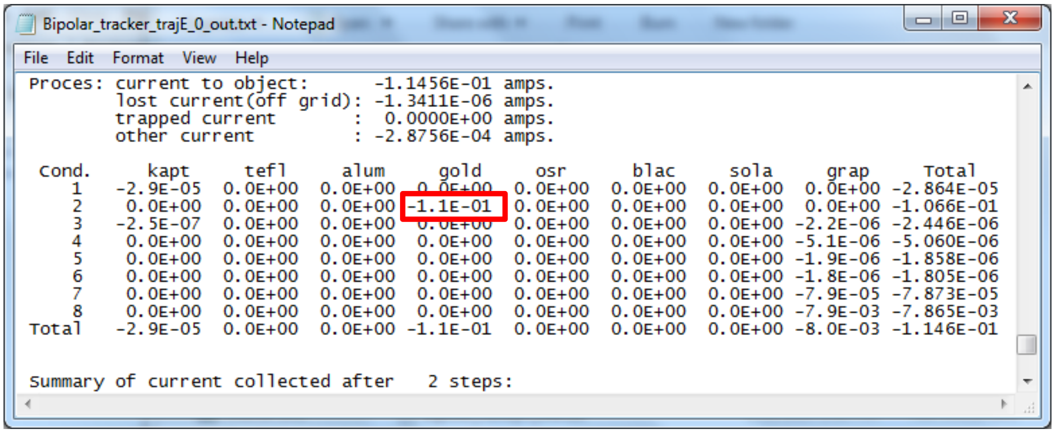


Bipolar_potent_0_out.txt - Notepad
File Edit Format View Help

```
PSprep -- Mix    0.00 % of old to new solution

PSprep -- Surface electric field limited.

PSprep -- ITime=  1 TotTim=  0.00E+00

Sheath boundary potentials:
Grid # 1 Ymesh=  1.000000 meters. SthPot=  4.344533 volts.
Grid # 2 Ymesh=  0.500000 meters. SthPot=  1.724129 volts.
Grid # 3 Ymesh=  0.250000 meters. SthPot=  0.684221 volts.
Grid # 4 Ymesh=  0.250000 meters. SthPot=  0.684221 volts.
Grid # 5 Ymesh=  0.125000 meters. SthPot=  0.271533 volts.
Grid # 6 Ymesh=  0.125000 meters. SthPot=  0.271533 volts.

ICLow =    0
Conductor potentials at time=  0.0000E+00 secs:
    ICond    Type                   Value       Biased From  PCond(Volts)
       1     Fixed_Potential        0.0000E+00        0      0.0000E+00
       2     Fixed_Potential        1.0000E+04        0      1.0000E+04
       3     Fixed_Potential        1.5000E+03        0      1.5000E+03
       4     Fixed_Potential        3.0000E+03        0      3.0000E+03
       5     Fixed_Potential        4.5000E+03        0      4.5000E+03
       6     Fixed_Potential        6.0000E+03        0      6.0000E+03
       7     Fixed_Potential        7.5000E+03        0      7.5000E+03
       8     Fixed_Potential        9.0000E+03        0      9.0000E+03
VXB = (  0.00E+00,  0.00E+00,  0.00E+00)
***TIMER*** MAIN: iteration    1
***TIMER*** Total Elapsed User Time =       22.776 Seconds.
psSCG: Begin ...
```

Figure 80. Partial Contents of the bipolar_potent_0_out.txt File Showing Highlighted Sheath Potential for Grid #2 for Case 1 of the "Bipolar" Example

Go to the **Script** tab. Notice that "*The Script is out of date!*" message has appeared. Build the script and run it. The inputs and results of the surface currents calculations of electron collection are in the following text files: **bipolar_partgen_Electron_0_in.txt**, **bipolar_partgen_Electron_0_out.txt**, **bipolar_tracker_trajE_0_in.txt**, and **bipolar_tracker_trajE_0_out.txt**. The electron current collected by the various object components is in **bipolar_tracker_trajE_0_out.txt**. As shown in Figure 81, the electron current collected by the gold-plated cube is 0.11 amperes, with 0.008 amperes collected by the 9 kV biased section of boom next to the cube, and small amounts of current collected by lower potential boom segments.



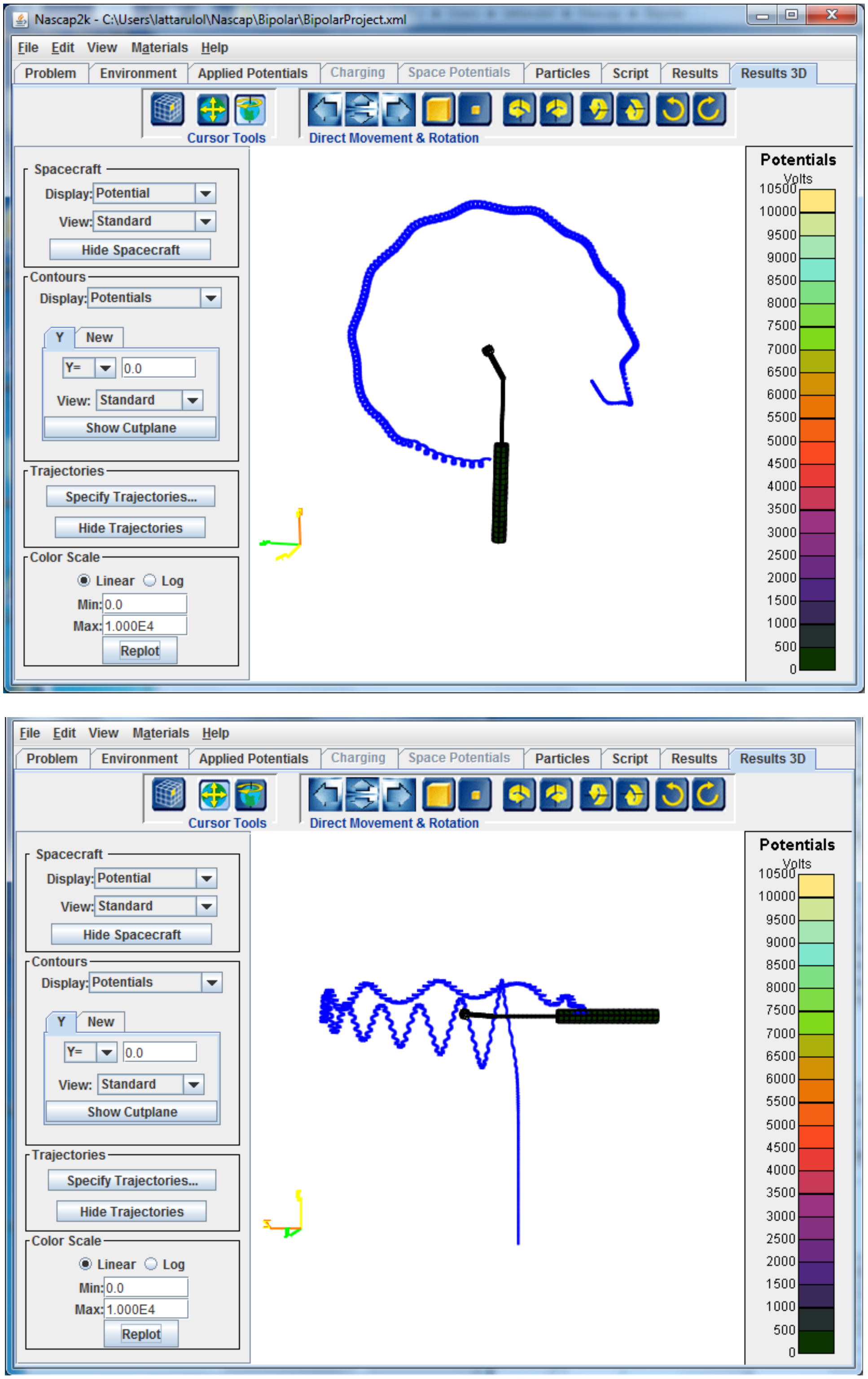
Bipolar_tracker_trajE_0_out.txt - Notepad
File Edit Format View Help

```
Proces: current to object:       -1.1456E-01 amps.
        lost current(off grid): -1.3411E-06 amps.
        trapped current        :  0.0000E+00 amps.
        other current          : -2.8756E-04 amps.

  Cond.     kapt      tefl      alum      gold      osr       blac      sola      grap      Total
    1    -2.9E-05  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00 -2.864E-05
    2     0.0E+00  0.0E+00  0.0E+00 -1.1E-01  0.0E+00  0.0E+00  0.0E+00  0.0E+00 -1.066E-01
    3    -2.5E-07  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00 -2.2E-06 -2.446E-06
    4     0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00 -5.1E-06 -5.060E-06
    5     0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00 -1.9E-06 -1.858E-06
    6     0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00 -1.8E-06 -1.805E-06
    7     0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00 -7.9E-05 -7.873E-05
    8     0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00 -7.9E-03 -7.865E-03
Total    -2.9E-05  0.0E+00  0.0E+00 -1.1E-01  0.0E+00  0.0E+00  0.0E+00 -8.0E-03 -1.146E-01


Summary of current collected after   2 steps:
```

Figure 81. Partial Contents of the bipolar_tracker_traj_0_out.txt File Showing Current Collection Results for Case 1 of the "Bipolar" Example

The next calculation involves electron current collection, but with a non-zero magnetic field. In general, the presence of a magnetic field reduces current collection and is particularly important in low Earth orbit environments involving large electron sheaths.

Earth's magnetic field in the environment chosen for this example is approximately 0.4 G. On the **Environment** tab, in the "Magnetic Field" subsection (Figure 70), we therefore impose Bx=0, By=4e-5, Bz=0 in tesla. On the **Surface Currents** subtab of the **Particles** tab, the sheath potential is once again the sheath edge potential, 1.724 V. Rerun the script. Note that the magnetic field orientation is chosen such that it is normal to the plane formed by the boom and rocket axis. In this configuration electrons **E×B** drift around the cube, in a plane with normal pointing in the same direction as the magnetic field (i.e., Y-direction). Figure 82 shows the **Results 3D** tab illustrating one electron trajectory in the presence of the non-zero magnetic field. The second view of the particle is to confirm that the tracked electron is leaving the grid. To view this trajectory, change the tracking limits to X=0.1 to 0.15, Y=-9 to 9, and Z=-5 to 0. We find that the computed electron current to the cube has been reduced from 106.9 mA to 8.47 mA as can be seen in the **bipolar_tracker_traj_0_out.txt** file.



Nascap2k - C:\Users\lattarulol\Nascap\Bipolar\BipolarProject.xml

Spacecraft
Display: Potential
View: Standard

Contours
Display: Potentials
Y= 0.0
View: Standard

Color Scale
● Linear ○ Log
Min: 0.0
Max: 1.000E4

Spacecraft
Display: Potential
View: Standard

Contours
Display: Potentials
Y= 0.0
View: Standard

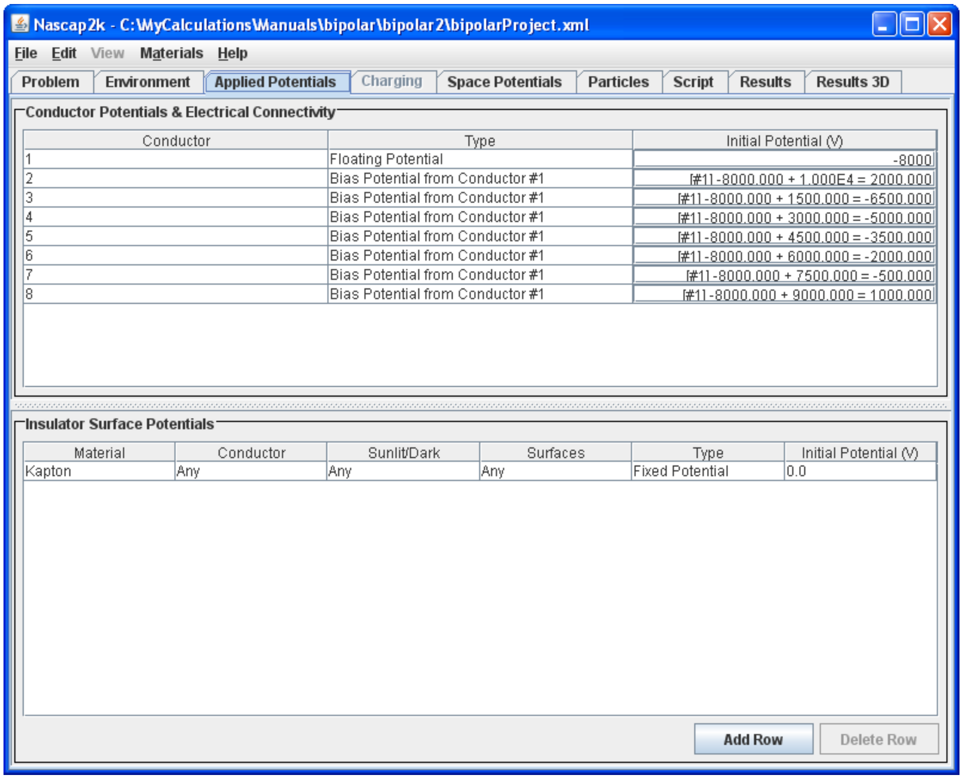
Color Scale
● Linear ○ Log
Min: 0.0
Max: 1.000E4

Figure 82. Electron Trajectories Around the Positively Biased Cube when Bx=0, By=0.4 G, Bz=0 for Case 1 of the "Bipolar" Example (Bottom is rotated view of top)

19.4 Case 2: Ion Collection

The next sample calculation, Case 2, involves ion current collection. Because the effect of the magnetic field on ion motion is negligible in this case, we set all components of the magnetic field in the **Environment** tab to zero. To create an ion-collecting sheath, we fix the body potential (conductor 1) to –8 kV as shown in Figure 83. Because the boom is covered with an insulating material and therefore has a surface floating potential of near zero, we set the boom surface potential to zero using the "Insulator Surface Potentials" portion of the tab.

As in Case 1, a sheath edge potential value is required before we can compute surface currents. Click the **Problem** tab, check "Potentials in Space," and uncheck "Surface Currents." Return to the **Script** tab and rebuild and run the script. Click the **Results 3D** tab to view the potentials. The potential calculation shows the ion sheath extending far beyond the electron sheath, with the first almost completely choking off the second (and thus reducing the effective electron-collecting sheath area). As illustrated in Figure 84 the sheath edge lies in grid #1, so the appropriate potential value to use on the **Surface Currents** subtab is 4.34 V. (This value is obtained by looking in the **bipolar_potent_0_out.txt** file as in section 19.3.2.) Click the **Problem** tab to specify "Surface Currents," then click the **Script** tab to build and run the new script. The ion current collected by the aluminum body is 2.156 mA, as seen in **bipolar_tracker_traj_0_out.txt.** Figure 85 shows ion trajectories using the sheath edge potential value of 4.34 V for the "Contour Initial Particle Distribution."



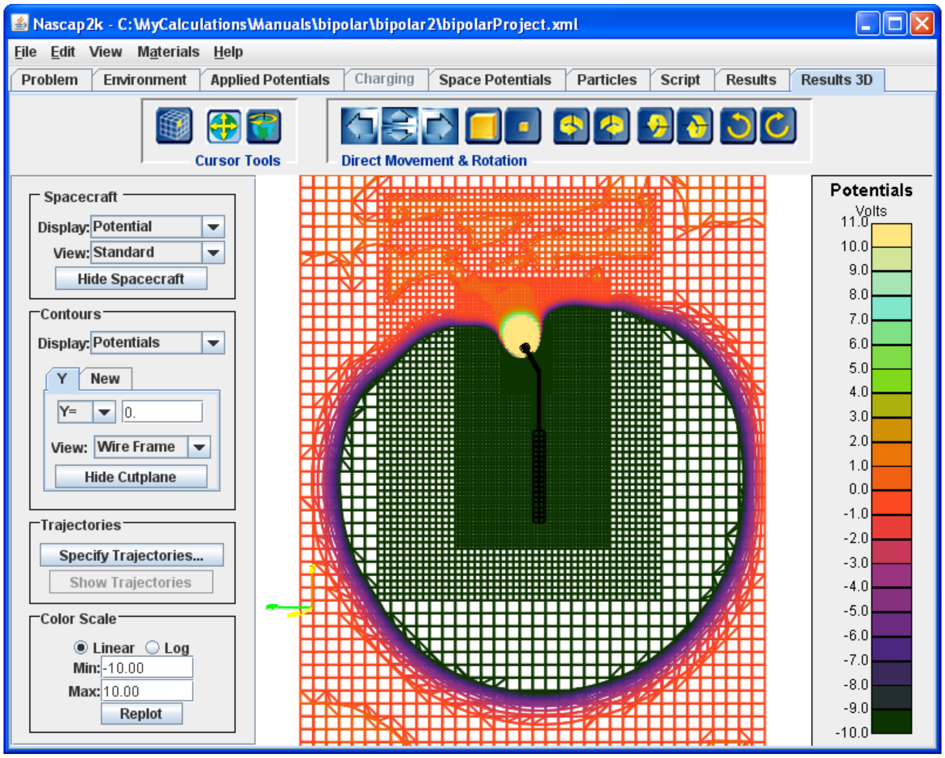
Conductor Potentials & Electrical Connectivity

Conductor	Type	Initial Potential (V)
1	Floating Potential	-8000
2	Bias Potential from Conductor #1	[#1] -8000.000 + 1.000E4 = 2000.000
3	Bias Potential from Conductor #1	[#1] -8000.000 + 1500.000 = -6500.000
4	Bias Potential from Conductor #1	[#1] -8000.000 + 3000.000 = -5000.000
5	Bias Potential from Conductor #1	[#1] -8000.000 + 4500.000 = -3500.000
6	Bias Potential from Conductor #1	[#1] -8000.000 + 6000.000 = -2000.000
7	Bias Potential from Conductor #1	[#1] -8000.000 + 7500.000 = -500.000
8	Bias Potential from Conductor #1	[#1] -8000.000 + 9000.000 = 1000.000

Insulator Surface Potentials

Material	Conductor	Sunlit/Dark	Surfaces	Type	Initial Potential (V)
Kapton	Any	Any	Any	Fixed Potential	0.0

Figure 83. Applied Potentials on Conductors and Insulators for Ion-current Collection Calculation for Case 2 of the "Bipolar" Example

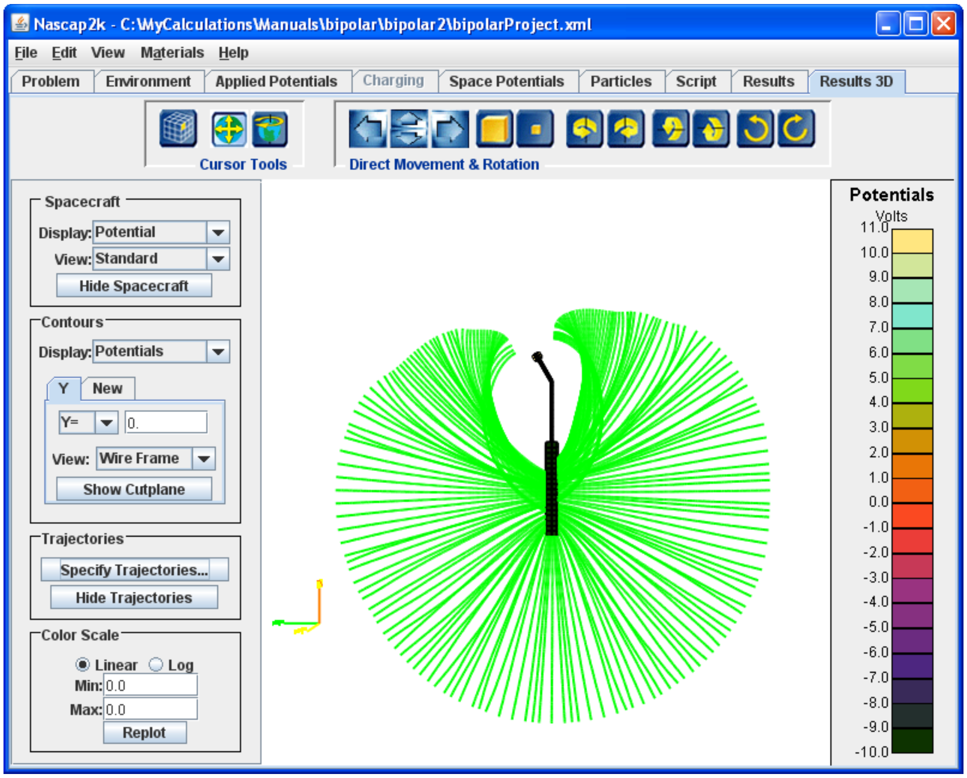

Nascap2k - C:\MyCalculations\Manuals\bipolar\bipolar2\bipolarProject.xml

Spacecraft — Display: Potential; View: Standard

Contours — Display: Potentials; Y= 0.; View: Wire Frame

Color Scale — ● Linear ○ Log; Min: -10.00; Max: 10.00

Figure 84. Potential Distribution Showing Ion and Electron Sheath Edges on the Mesh for Case 2 of the "Bipolar" Example


Nascap2k - C:\MyCalculations\Manuals\bipolar\bipolar2\bipolarProject.xml

Spacecraft — Display: Potential; View: Standard

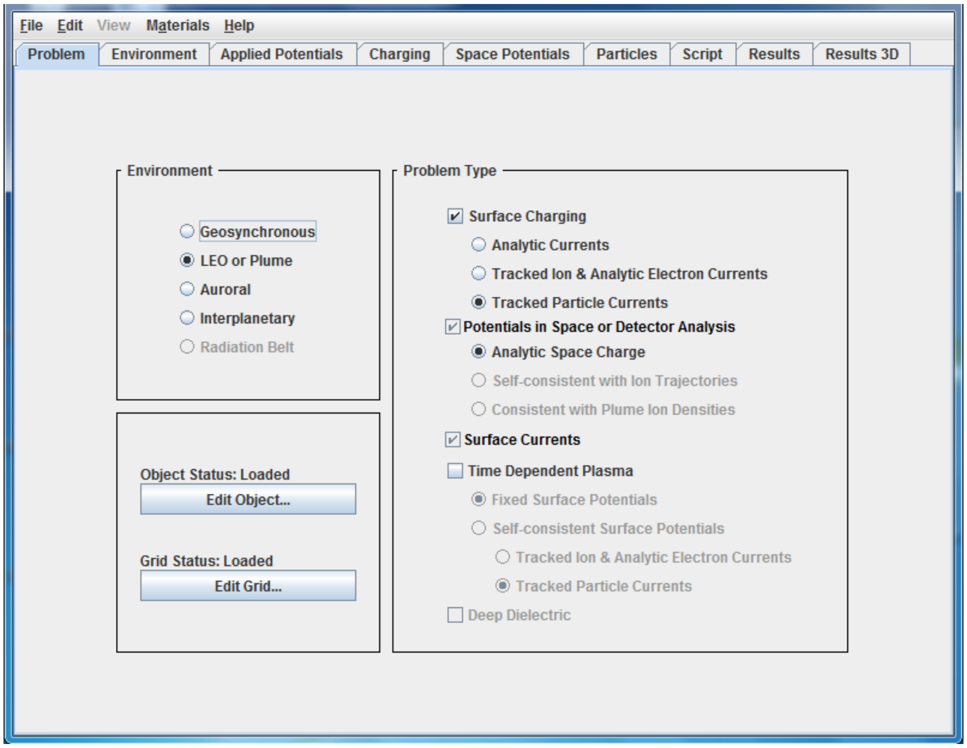
Contours — Display: Potentials; Y= 0.; View: Wire Frame

Color Scale — ● Linear ○ Log; Min: 0.0; Max: 0.0

Figure 85. Oxygen Ion Trajectories for Case 2 of the "Bipolar" Example

19.5 Case 3: Current Balance

We can calculate the steady-state rocket body and cube floating potentials, determined by the condition of zero net current. As we are again tracking electrons, we make sure that the magnetic field is set to (0, 4e-5, 0) tesla on the **Environment** tab. We use the model for charging using "Tracked Particle Currents" as shown on the **Problem** tab (Figure 86). This consists of iteratively calculating space potentials, tracked sheath currents, and surface charging due to those currents. The **Applied Potentials** (showing the change from fixed to floating boundary conditions on Conductor #1) and the **Charging** tabs are shown in Figure 87 and Figure 88, respectively. Two microseconds of charging are specified for each iteration of the space potential calculation and 100 microseconds for the total charging time. This time does *not* correspond to real time, but must be short for stability. The total number of timesteps is 75, which is also displayed on the **Space Potentials** tab (Figure 89) as the "Number of Iterations." Also on this tab, be sure to update the Target Average (RMS) Error to what is shown. Because both species must be tracked, both "Electron" and "Oxygen" are highlighted on the **Surface Currents** subtab of the **Particles** tab (Figure 90). Notice that the chosen sheath edge potential value is the one for ions (4.344 V). For this problem the difference in the electron current using the electron sheath potential rather than that of ions is negligible. As it does affect the ion current, we use the value for the ion sheath edge. In this version of *Nascap-2k*, the user interface is not set up to handle different sheath potentials for the different species. (It is possible to do this by directly editing the input files for the Create **Particles** module) As usual, rebuild and rerun the script. *Note that this calculation can take a couple of hours* depending on the speed of the computer



Environment

○ Geosynchronous
● LEO or Plume
○ Auroral
○ Interplanetary
○ Radiation Belt

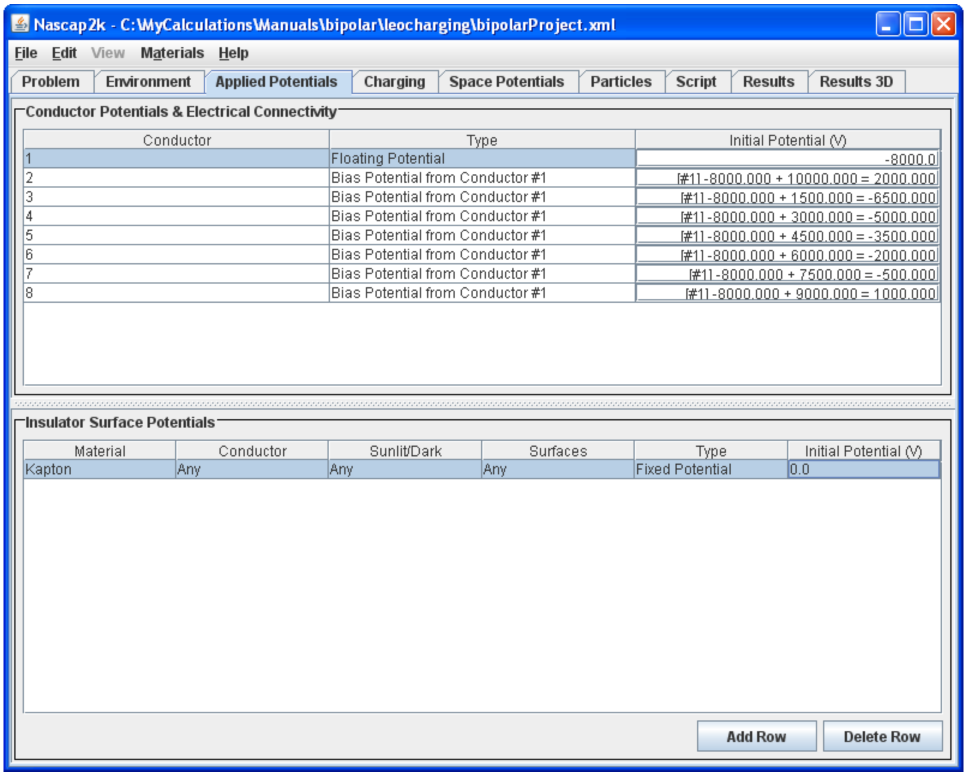
Object Status: Loaded

Grid Status: Loaded

Problem Type

☑ Surface Charging
○ Analytic Currents
○ Tracked Ion & Analytic Electron Currents
● Tracked Particle Currents
☑ Potentials in Space or Detector Analysis
● Analytic Space Charge
○ Self-consistent with Ion Trajectories
○ Consistent with Plume Ion Densities
☑ Surface Currents
□ Time Dependent Plasma
● Fixed Surface Potentials
○ Self-consistent Surface Potentials
○ Tracked Ion & Analytic Electron Currents
● Tracked Particle Currents
□ Deep Dielectric

Figure 86. Problem Tab for Case 3 of the "Bipolar" Example


Nascap2k - C:\MyCalculations\Manuals\bipolar\leocharging\bipolarProject.xml
File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D

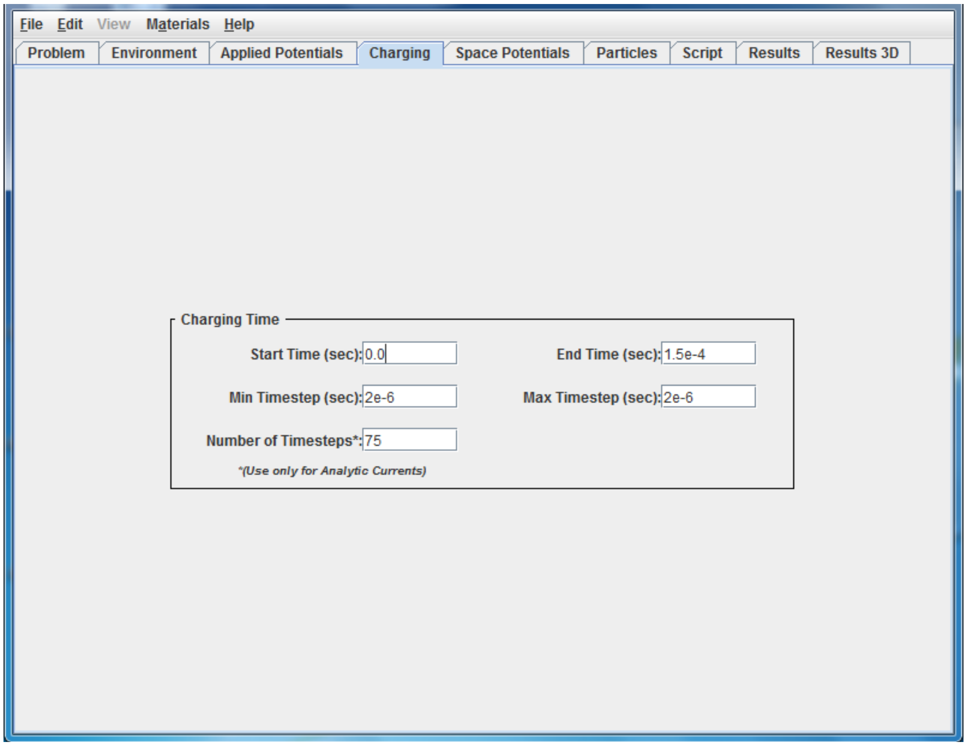
Conductor Potentials & Electrical Connectivity

Conductor	Type	Initial Potential (V)
1	Floating Potential	-8000.0
2	Bias Potential from Conductor #1	[#1] -8000.000 + 10000.000 = 2000.000
3	Bias Potential from Conductor #1	[#1] -8000.000 + 1500.000 = -6500.000
4	Bias Potential from Conductor #1	[#1] -8000.000 + 3000.000 = -5000.000
5	Bias Potential from Conductor #1	[#1] -8000.000 + 4500.000 = -3500.000
6	Bias Potential from Conductor #1	[#1] -8000.000 + 6000.000 = -2000.000
7	Bias Potential from Conductor #1	[#1] -8000.000 + 7500.000 = -500.000
8	Bias Potential from Conductor #1	[#1] -8000.000 + 9000.000 = 1000.000

Insulator Surface Potentials

Material	Conductor	Sunlit/Dark	Surfaces	Type	Initial Potential (V)
Kapton	Any	Any	Any	Fixed Potential	0.0

Figure 87. Applied Potentials Tab for Case 3 of the “Bipolar” Example


File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D

Charging Time

Start Time (sec): 0.0

End Time (sec): 1.5e-4

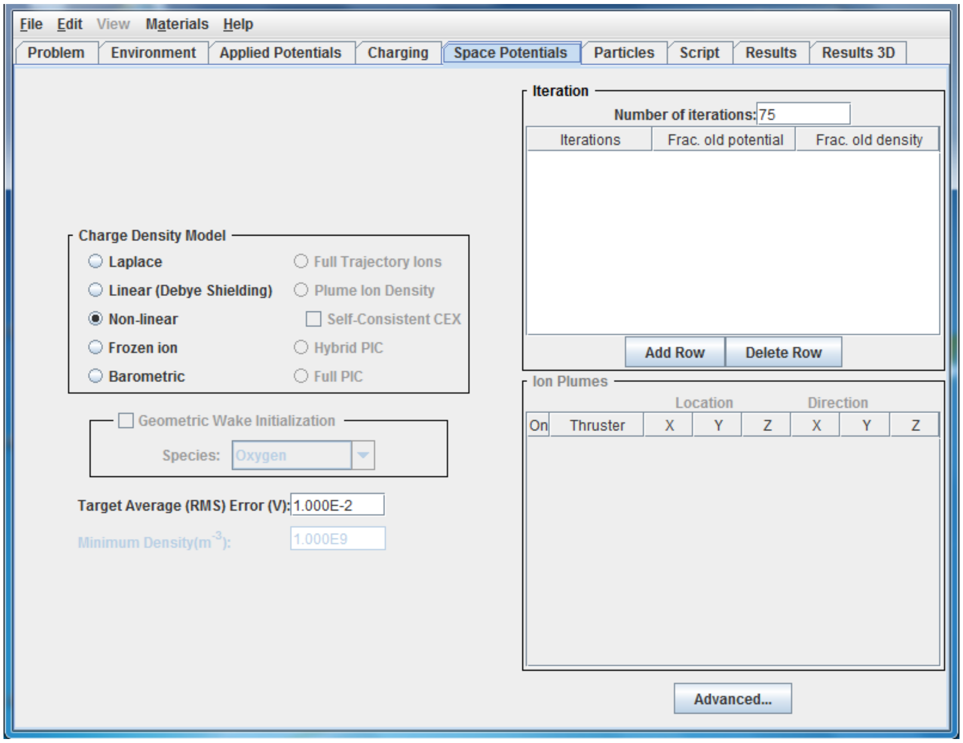
Min Timestep (sec): 2e-6

Max Timestep (sec): 2e-6

Number of Timesteps*: 75

(Use only for Analytic Currents)

Figure 88. Charging Tab for Case 3 of the “Bipolar” Example



Iteration

Number of iterations: 75

Iterations	Frac. old potential	Frac. old density

Charge Density Model

○ Laplace
○ Linear (Debye Shielding)
● Non-linear
○ Frozen ion
○ Barometric
○ Full Trajectory Ions
○ Plume Ion Density
□ Self-Consistent CEX
○ Hybrid PIC
○ Full PIC

□ Geometric Wake Initialization

Species: Oxygen

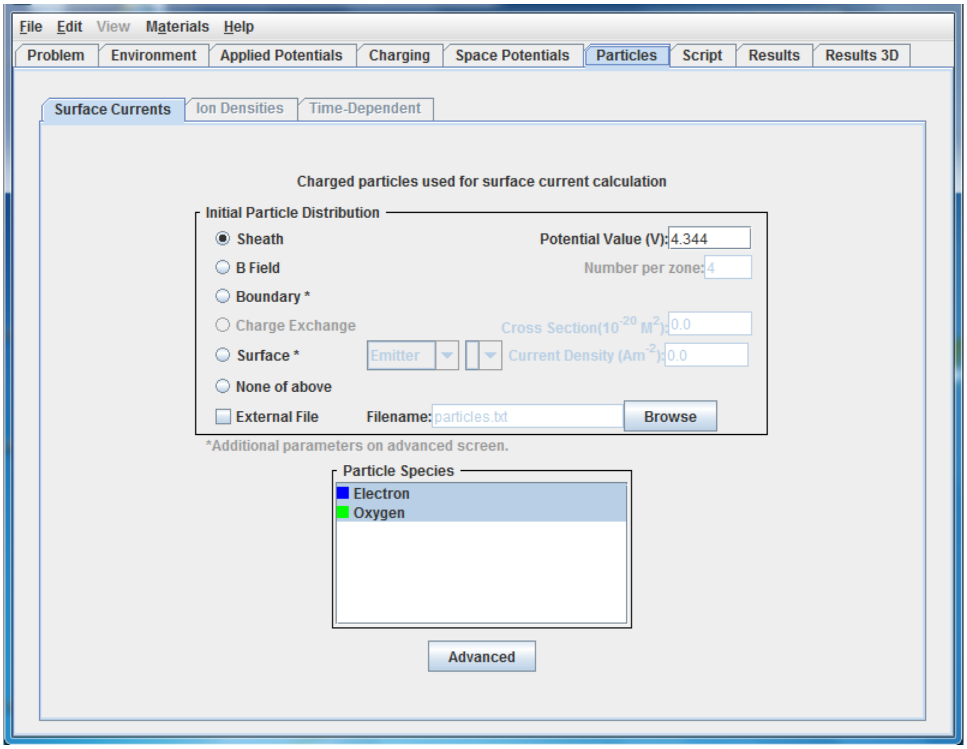
Target Average (RMS) Error (V): 1.000E-2

Minimum Density(m^{-3}): 1.000E9

Ion Plumes

		Location			Direction		
On	Thruster	X	Y	Z	X	Y	Z

Figure 89. Space Potentials Tab Showing Number of Iterations for Case 3 of the “Bipolar” Example



Charged particles used for surface current calculation

Initial Particle Distribution

● Sheath
○ B Field
○ Boundary *
○ Charge Exchange
○ Surface *
○ None of above
□ External File

Potential Value (V): 4.344

Number per zone: 4

Cross Section(10^{-20} M^2): 0.0

Emitter

Current Density (Am^{-2}): 0.0

Filename: particles.txt

*Additional parameters on advanced screen.

Particle Species

🟦 Electron
🟩 Oxygen

Figure 90. Surface Current Subtab for Case 3 of the “Bipolar” Example

Figure 91 illustrates a plot on the **Results** tab of the potential as a function of time for Conductors #1 (rocket body only because boom potential has been fixed to 0 V) and #2 (cube).

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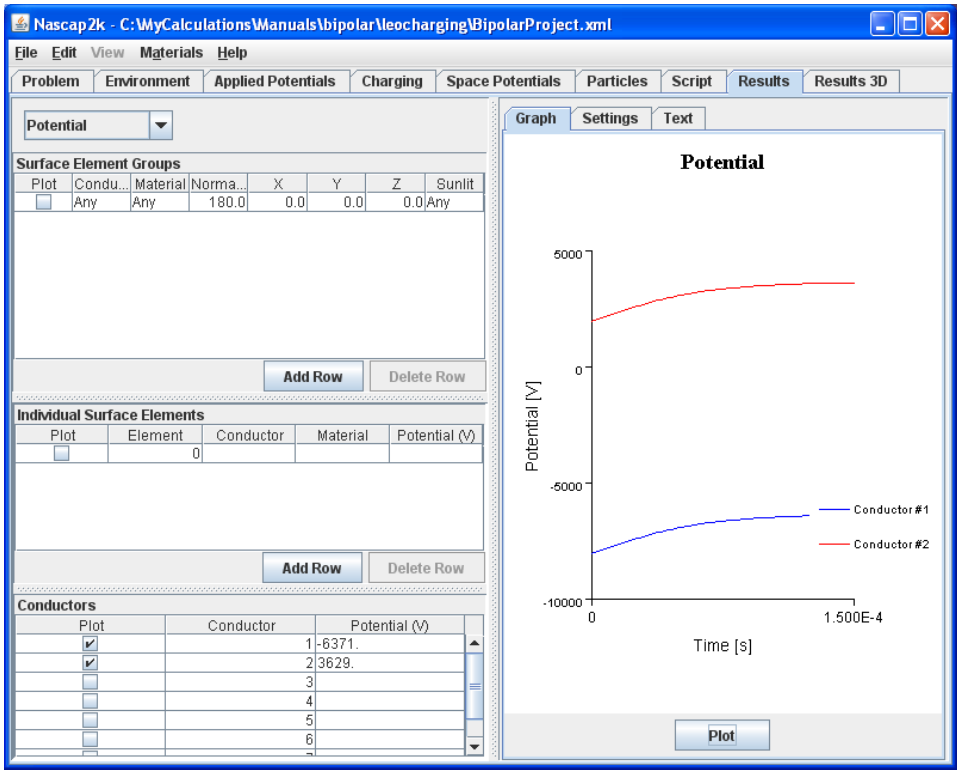
The plots show that steady-state is reached. (The time parameter is nonphysical.) The **Settings** subtab may be used to adjust the graph properties, such as axis limits. The **Text** subtab may be used to transfer the current collection results (in tabular format) to a spreadsheet and plot the evolution to current balance as shown in Figure 92. Ion and electron currents are tracked separately, so one must alternatively select “Tracked Current” and “Tracked Electron Current” on the drop-down list to plot the different values. The equilibrium values of the potentials for the body and gold cube are –6.4 kV and 3.6 kV, respectively, as shown in Figure 91. The collected values are electron current to cube = 1.8 mA, electron current to bushing = 0.26 mA, and ion current = 2.1 mA as shown in Figure 92. The potential distribution and trajectories are shown in Figure 93 and Figure 94, respectively.

When interpreting the calculation’s results, it is important to remember that any secondary electrons created by the incident 6.7 keV ions are *not* included in the calculation. For many materials, each incident ion generates several electrons, effectively multiplying the incident ion current. The extra current source dramatically increases (i.e., makes less negative) the chassis potential at which current balance is achieved.



Potential

Surface Element Groups

Plot	Condu...	Material	Norma...	X	Y	Z	Sunlit
□	Any	Any	180.0	0.0	0.0	0.0	Any

Individual Surface Elements

Plot	Element	Conductor	Material	Potential (V)
□	0			

Conductors

Plot	Conductor	Potential (V)
☑	1	-6371.
☑	2	3629.
□	3	
□	4	
□	5	
□	6	

Figure 91. Results Tab Showing Evolution of Conductor Potentials Toward Current Balance for Case 3 of the “Bipolar” Example

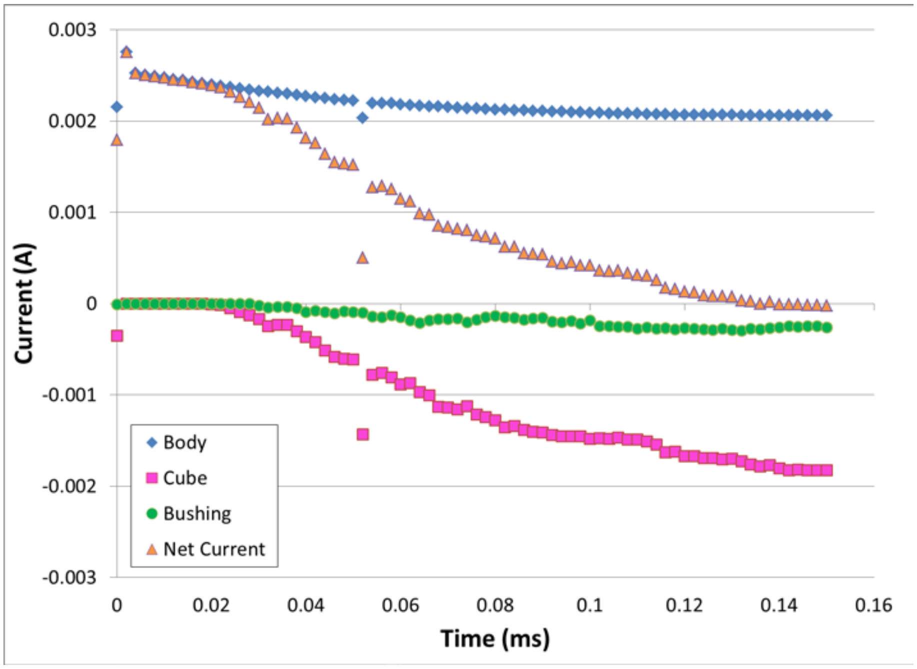
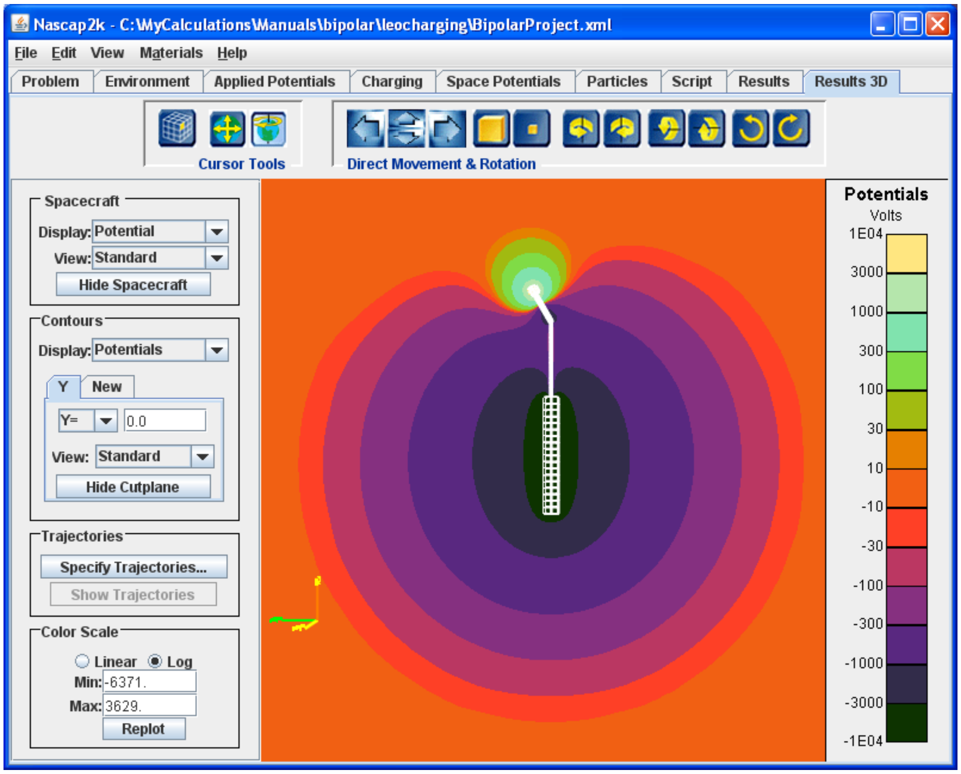
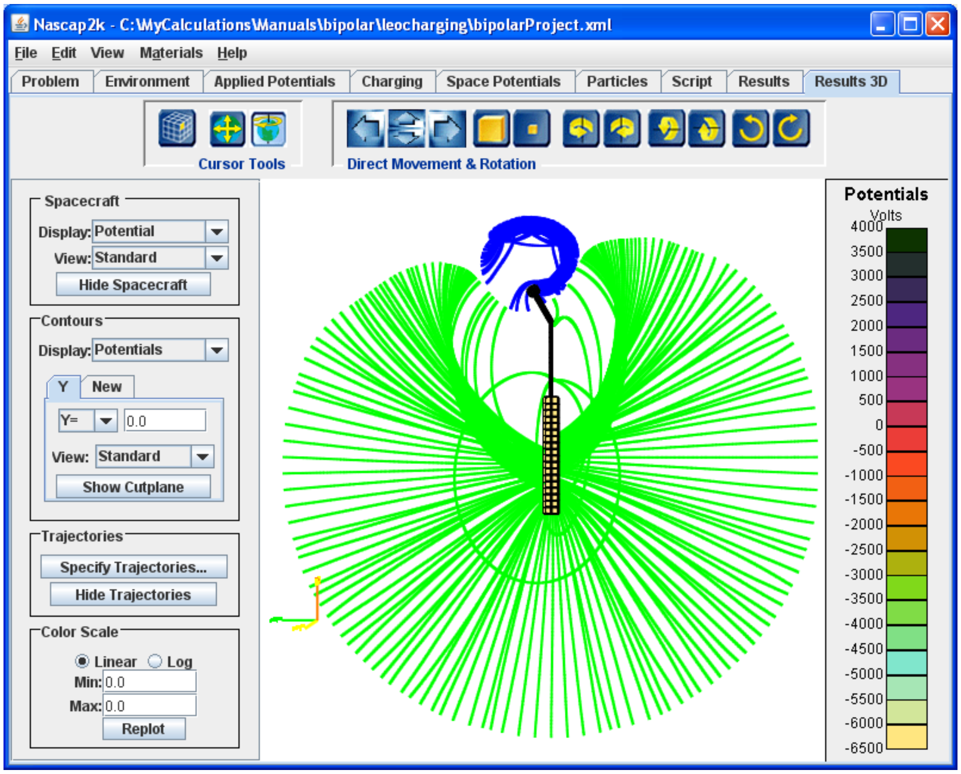


Figure 92. Current Collection by Conductors as a Function of Time for Case 3 of the "Bipolar" Example


Nascap2k - C:\MyCalculations\Manuals\bipolar\leocharging\BipolarProject.xml

Display: Potential
View: Standard
Display: Potentials
Y= 0.0
View: Standard
○ Linear ● Log
Min: -6371.
Max: 3629.

Figure 93. Potential Distribution at Equilibrium (~Zero Net Current) in the "Bipolar" Example


Nascap2k - C:\MyCalculations\Manuals\bipolar\leocharging\bipolarProject.xml

Spacecraft
Display: Potential
View: Standard

Contours
Display: Potentials
Y= 0.0
View: Standard

Color Scale
● Linear ○ Log
Min: 0.0
Max: 0.0

Figure 94. Selected Ion and Electron Trajectories at Equilibrium in the "Bipolar" Example

20 Wake Effects and Current Collection in Low Earth Orbit (example name: "CHAWS")

20.1 Background

When a high-speed spacecraft moves through the ambient plasma, two main regions form: a compression region in the ram, and a rarefaction or "wake" region behind the body. In general, the structure of the wake depends on a variety of factors. For example, the spacecraft's velocity (both the magnitude and angle of attack), the (applied) potential on the back surface of the structure, and the ambient (or induced) magnetic field may all play a determining factor in the wake's formation. Under certain simplifying assumptions an analytical solution can be obtained. For example, assuming quasi-neutral flow over a biased plate for which the sheath can be ignored, the solution is identical to that of a supersonic flow over a convex corner (which leads to an expansion fan) and may therefore be obtained using a standard Prandtl-Meyer formulation. In most practical problems, however, such as highly-biased spacecraft in low Earth orbit, the sheath may not be ignored and the wake structure must be found numerically.

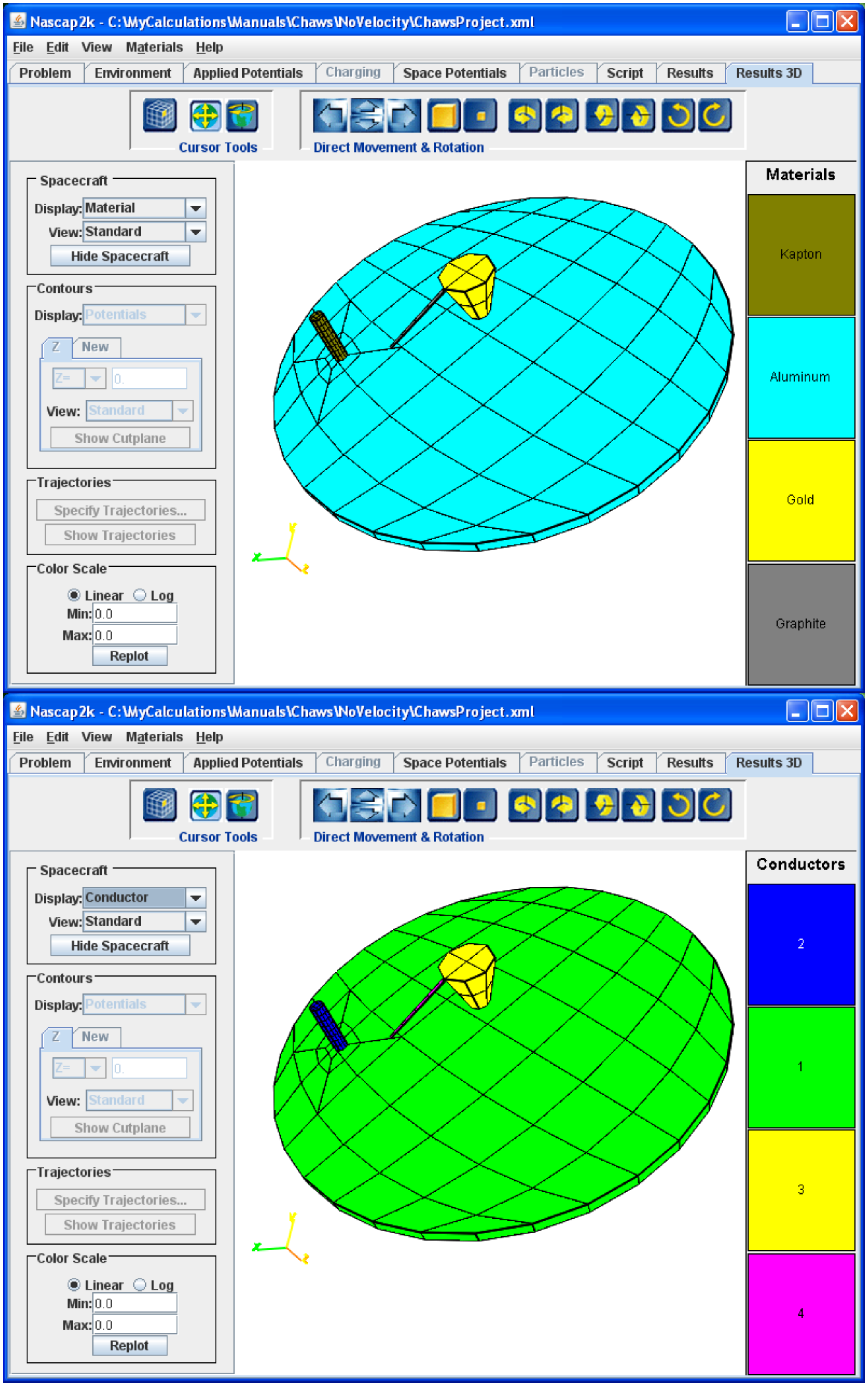
A spacecraft in low Earth orbit moves at a speed of about 7800 km/s. This speed is about seven times the local thermal speed of O^+ ions, but less than the electron thermal speed. To investigate high-voltage current collection within the spacecraft wake in low Earth orbit, the Air Force (then Philips Laboratory, now the Air Force Research Laboratory) sponsored the Charge Hazards and Wake Studies[4] (CHAWS) experiment. CHAWS flew on the Wake Shield Facility (WSF). The following example uses a model object of the WSF and *Nascap-2k* to compute space potentials and current collection in wake-type problems such as CHAWS. To illustrate some main features in this kind of problem, space potentials and ion current collected results are shown for

(1) stationary spacecraft, (2) plasma density calculated in the neutral approximation and space-charge density calculated using an analytic model, (3) space charge density calculated using the self-consistent with ion trajectories approach, and (4) same as (3), for a 10% hydrogen plasma.

20.2 Object and Grid Definition

First, make a new project (CHAWS1, for example) and import the CHAWS object, which is in the **Nascap2k_4/Manual/Example Problems/CHAWS** folder. The WSF object is depicted in Figure 95. It consists mainly of a disk of radius 1.83 m and thickness of 9.54 cm and a cylindrical probe. The probe has a diameter of 10.8 cm and is 45.7 cm long, separated by 1.3 cm from the disk. The large yellow object was part of the epitaxy experiment, which was the main WSF objective and contained an oven and ion gun, and shot ions toward another part of the experiment located on the back of the shield. The other object appearing in Figure 95 is one of the mounting struts for the epitaxy experiment. Other portions of the structure were sufficiently removed from the ion stream that they had no effect on the probe measurements.

Click “Edit Grid” and import the CHAWS object and the grid which is also in the **Nascap2k_4/Manual/Example Problems/CHAWS** folder. The mesh is shown in Figure 96. It incorporates a total of 15 grids. The specifications of the largest grid (#1), and the grid in the immediate vicinity of the probe (#8) are also shown in Figure 96.



Nascap2k - C:\MyCalculations\Manuals\Chaws\NoVelocity\ChawsProject.xml

Spacecraft Display: Material

View: Standard

Color Scale: ● Linear ○ Log

Min: 0.0

Max: 0.0

Nascap2k - C:\MyCalculations\Manuals\Chaws\NoVelocity\ChawsProject.xml

Spacecraft Display: Conductor

View: Standard

Color Scale: ● Linear ○ Log

Min: 0.0

Max: 0.0

Figure 95. WSF Object. Top: Materials; Bottom: Conductors

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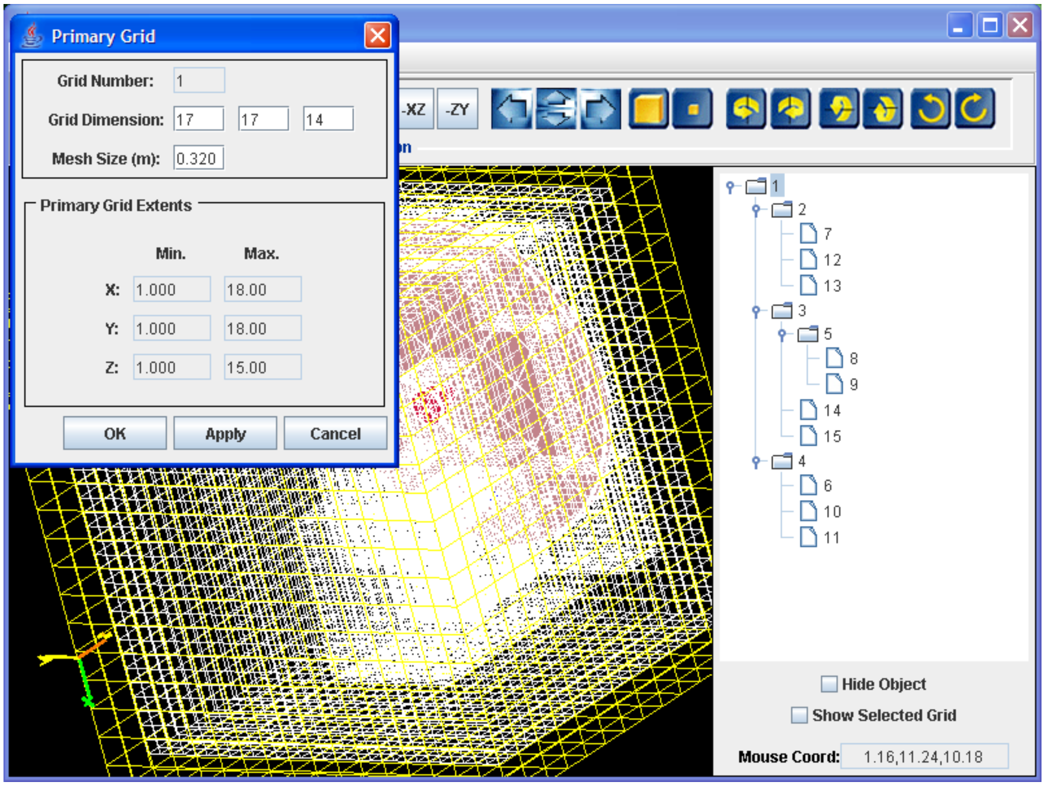

Primary Grid

Grid Number: 1

Grid Dimension: 17 17 14

Mesh Size (m): 0.320

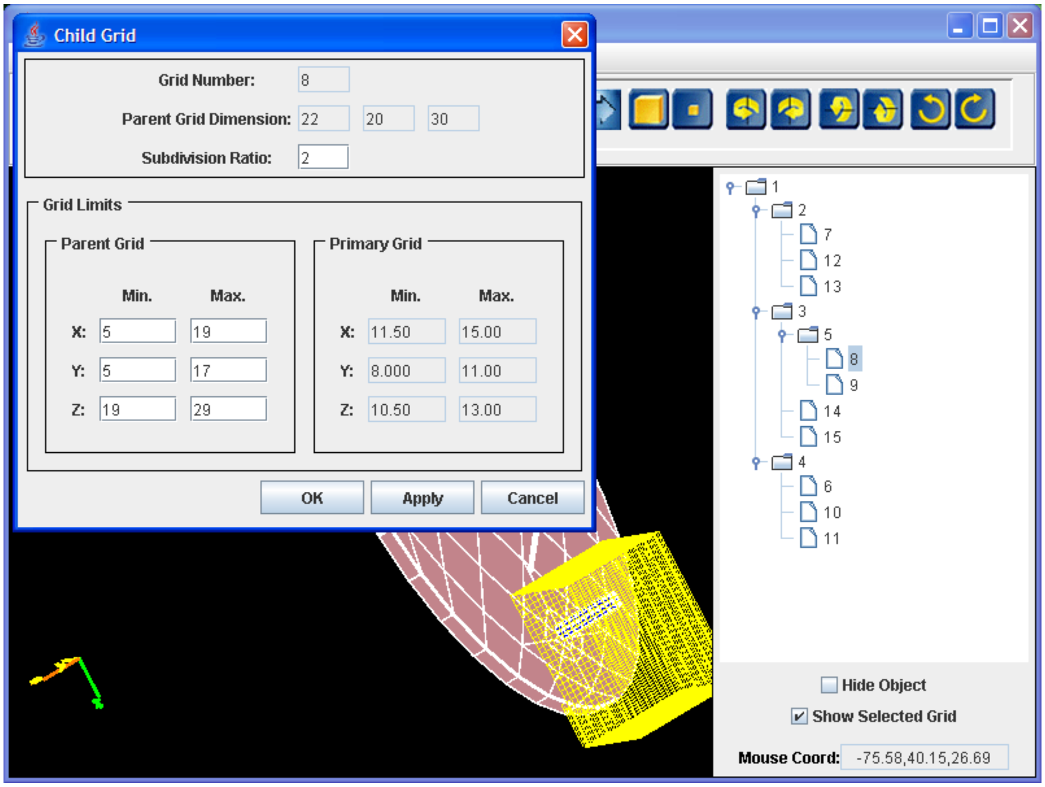
Primary Grid Extents

	Min.	Max.
X:	1.000	18.00
Y:	1.000	18.00
Z:	1.000	15.00

☐ Hide Object

☐ Show Selected Grid

Mouse Coord: 1.16,11.24,10.18


Child Grid

Grid Number: 8

Parent Grid Dimension: 22 20 30

Subdivision Ratio: 2

Grid Limits

Parent Grid

	Min.	Max.
X:	5	19
Y:	5	17
Z:	19	29

Primary Grid

	Min.	Max.
X:	11.50	15.00
Y:	8.000	11.00
Z:	10.50	13.00

☐ Hide Object

☑ Show Selected Grid

Mouse Coord: -75.58,40.15,26.69

Figure 96. Grid Used to Calculate Electric Potentials around WSF. Top: All Nested 15 Grids Highlighting Grid #1. Bottom: Grid #8 (Surrounding the Cylindrical Probe)

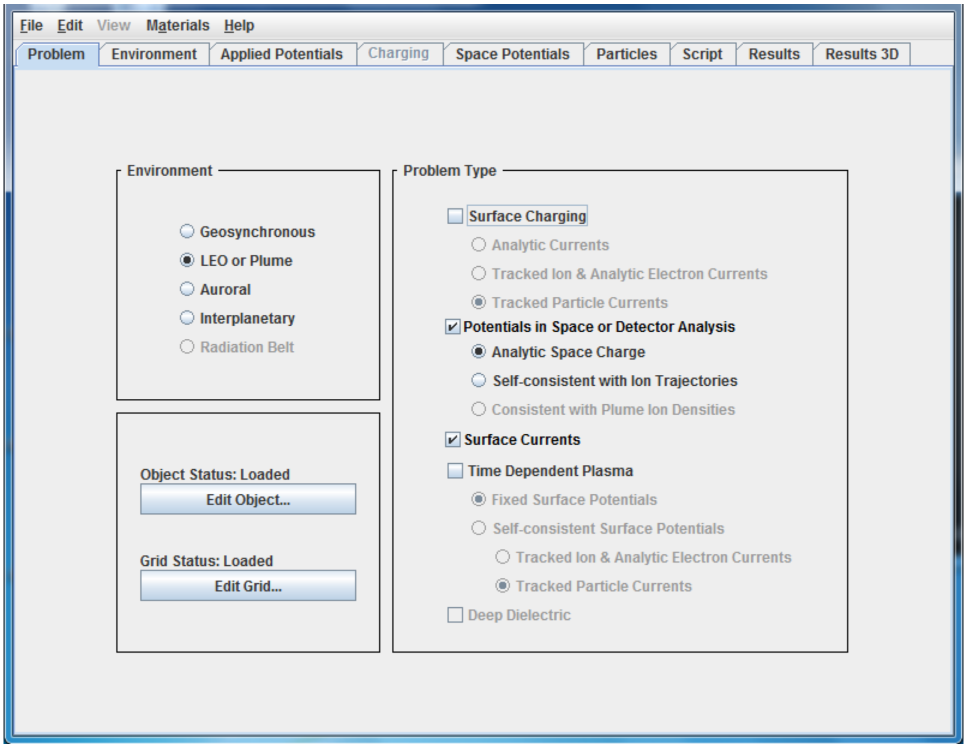
20.3 Calculating Space Potentials and Current Collection in the Wake

20.3.1 Case 1: Current Collection by a Stationary Spacecraft.

We begin the example by assuming a motionless spacecraft, and compute space potentials and current collection in an “LEO or Plume” environment using an “Analytic Space Charge” formulation for “Potentials in Space or Detector Analysis” and requesting “Surface Currents.” Thus the **Problem** tab is as shown in Figure 97. Figure 98 shows the **Environment** tab illustrating use of a moderately dense low Earth-orbit plasma, 10^{11} m^{-3} at 0.1 eV. No spacecraft velocity is imposed and only oxygen ions are considered in this case.

Figure 99 shows the **Applied Potentials** tab. The WSF (disk) is held at ground and the probe is biased to -2 kV relative to the disk.

Figure 100 shows the **Space Potentials** tab with the “Non-Linear” charge density checked.



Environment

○ Geosynchronous
● LEO or Plume
○ Auroral
○ Interplanetary
○ Radiation Belt

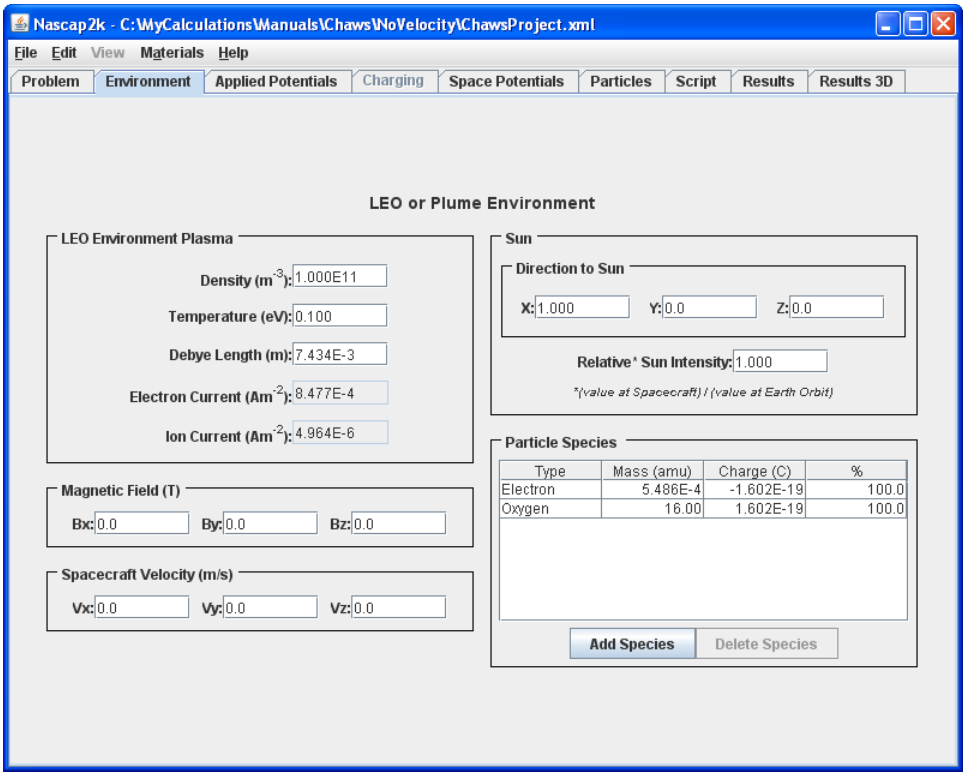
Object Status: Loaded

Grid Status: Loaded

Problem Type

☐ Surface Charging
○ Analytic Currents
○ Tracked Ion & Analytic Electron Currents
● Tracked Particle Currents
☑ Potentials in Space or Detector Analysis
● Analytic Space Charge
○ Self-consistent with Ion Trajectories
○ Consistent with Plume Ion Densities
☑ Surface Currents
☐ Time Dependent Plasma
● Fixed Surface Potentials
○ Self-consistent Surface Potentials
○ Tracked Ion & Analytic Electron Currents
● Tracked Particle Currents
☐ Deep Dielectric

Figure 97. Problem Tab for Case 1 of the “CHAWS” Example


Nascap2k - C:\MyCalculations\Manuals\Chaws\NoVelocity\ChawsProject.xml
File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D

LEO or Plume Environment

LEO Environment Plasma

Density (m^{-3}): 1.000E11

Temperature (eV): 0.100

Debye Length (m): 7.434E-3

Electron Current (Am^{-2}): 8.477E-4

Ion Current (Am^{-2}): 4.964E-6

Magnetic Field (T)

Bx: 0.0 By: 0.0 Bz: 0.0

Spacecraft Velocity (m/s)

Vx: 0.0 Vy: 0.0 Vz: 0.0

Sun

Direction to Sun

X: 1.000 Y: 0.0 Z: 0.0

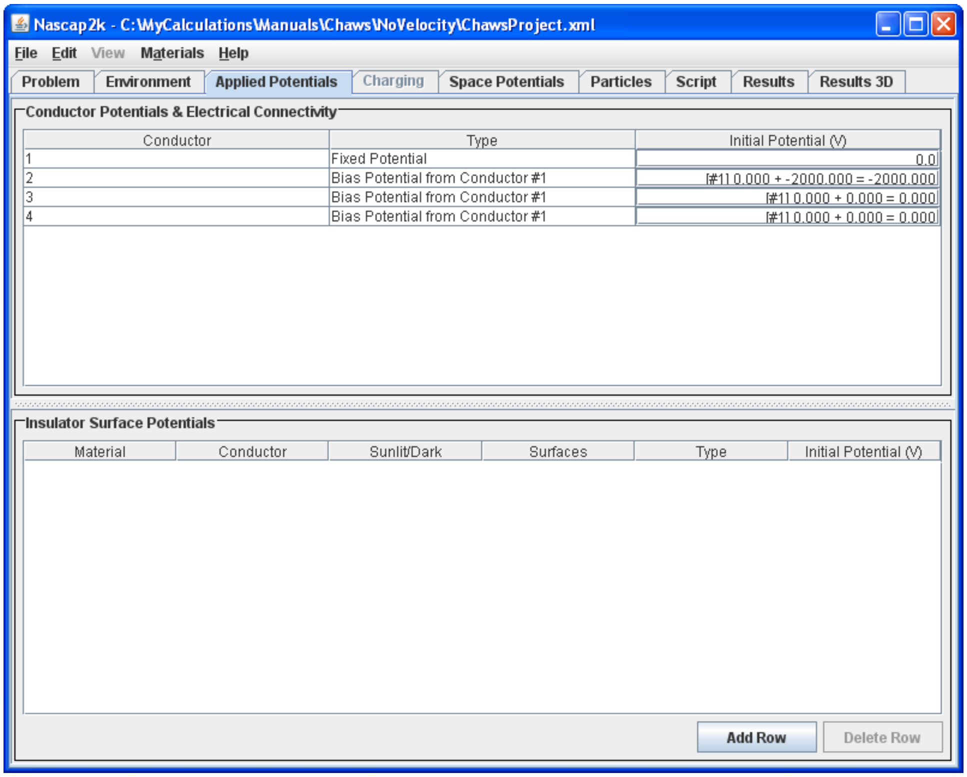
Relative* Sun Intensity: 1.000

*(value at Spacecraft) / (value at Earth Orbit)

Particle Species

Type	Mass (amu)	Charge (C)	%
Electron	5.486E-4	-1.602E-19	100.0
Oxygen	16.00	1.602E-19	100.0

Figure 98. Environment Tab for Case 1 of the “CHAWS” Example


Nascap2k - C:\MyCalculations\Manuals\Chaws\NoVelocity\ChawsProject.xml
File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D

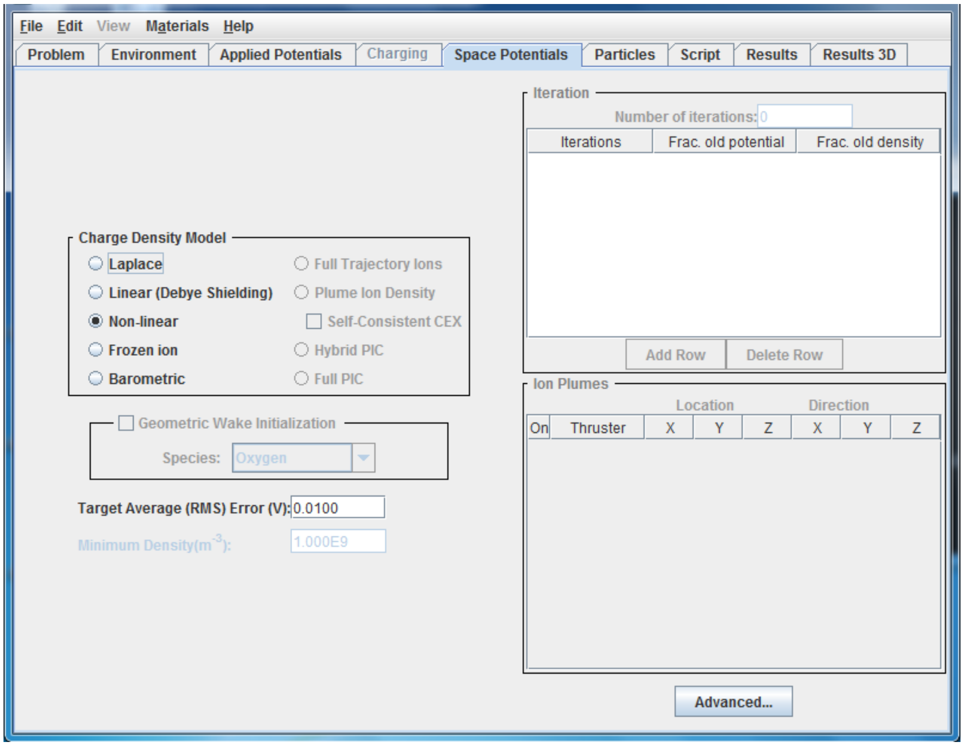
Conductor Potentials & Electrical Connectivity

Conductor	Type	Initial Potential (V)
1	Fixed Potential	0.0
2	Bias Potential from Conductor #1	[#1] 0.000 + -2000.000 = -2000.000
3	Bias Potential from Conductor #1	[#1] 0.000 + 0.000 = 0.000
4	Bias Potential from Conductor #1	[#1] 0.000 + 0.000 = 0.000

Insulator Surface Potentials

Material	Conductor	Sunlit/Dark	Surfaces	Type	Initial Potential (V)

Figure 99. Applied Potentials Tab for the “CHAWS” Example



Iteration

Number of iterations: 0

Iterations	Frac. old potential	Frac. old density

Charge Density Model

○ Laplace
○ Linear (Debye Shielding)
● Non-linear
○ Frozen ion
○ Barometric
○ Full Trajectory Ions
○ Plume Ion Density
□ Self-Consistent CEX
○ Hybrid PIC
○ Full PIC

□ Geometric Wake Initialization

Species: Oxygen

Target Average (RMS) Error (V): 0.0100

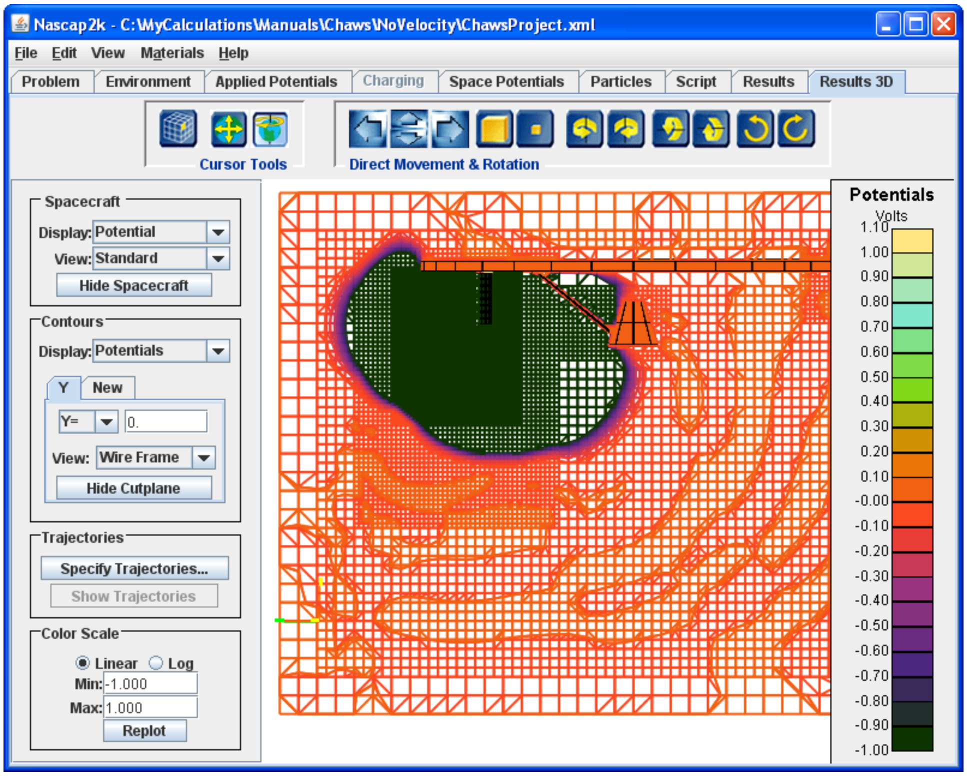
Minimum Density(m^{-3}): 1.000E9

Ion Plumes

		Location			Direction		
On	Thruster	X	Y	Z	X	Y	Z

Figure 100. Space Potentials Tab for Case 1 of the "CHAWS" Example

To compute ion current collection we select the "Sheath" option for the initial particle distribution on the **Surface Currents** subtab of the **Particles** tab. As in the "Bipolar" example, we must supply an appropriate value of the sheath edge potential. Figure 101 shows that the sheath edge lies in a number of grids (1, 11, 15, 5, 4), but mostly in Grid #5. (See also Figure 96.) We therefore choose 0.238 V as given in the **Potentials in Space** output file. As an accuracy check, the user can always perform a sensitivity analysis by comparing results using a sheath edge potential that corresponds to a different grid, e.g., #4. Figure 102 shows the **Surface Currents** subtab of the **Particles** tab. The potential profile, after running the script (Figure 103), is shown in Figure 104. To display (or hide) the cut plane, click on the "Show (Hide) Cut Plane" button. The **Track Particles** output file gives the collected oxygen ion current to the probe as 91 μA.



Display: Potential

View: Standard

Display: Potentials

Y= 0.

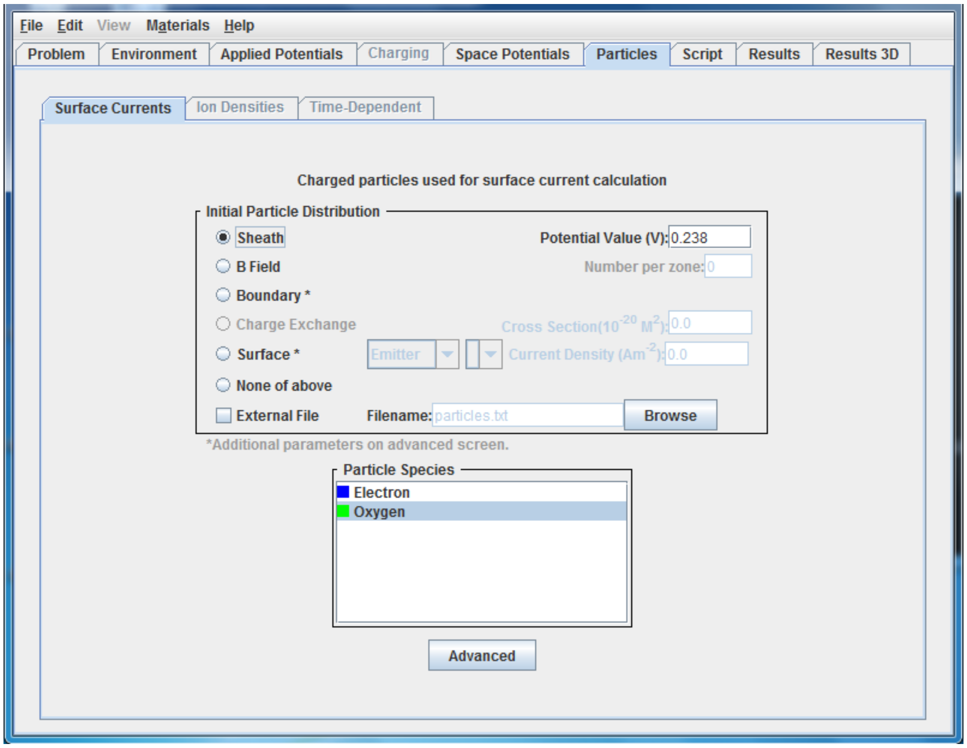
View: Wire Frame

● Linear ○ Log

Min: -1.000

Max: 1.000

Figure 101. Location of Sheath Edge Potential for Case 1 of the "CHAWS" Example


File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D
Surface Currents Ion Densities Time-Dependent
Browse
Advanced

Charged particles used for surface current calculation

Initial Particle Distribution

● Sheath — Potential Value (V): 0.238

○ B Field — Number per zone: 0

○ Boundary *

○ Charge Exchange — Cross Section(10^{-20} M^2): 0.0

○ Surface * — Emitter — Current Density (Am^{-2}): 0.0

○ None of above

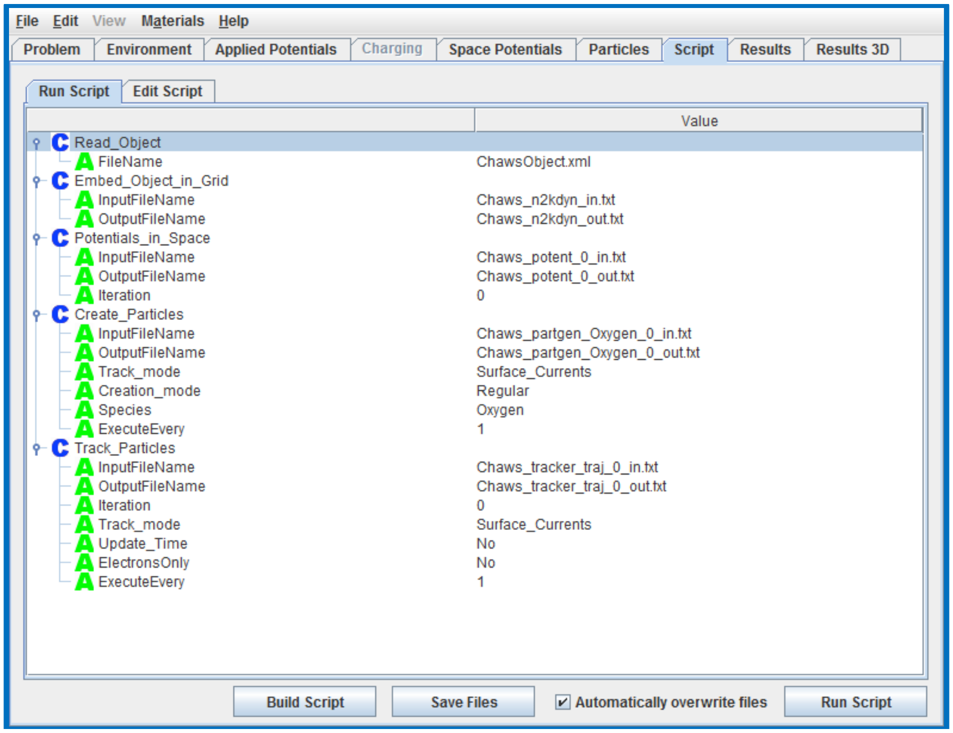
□ External File — Filename: particles.txt

*Additional parameters on advanced screen.

Particle Species

- 🟦 Electron
- 🟩 Oxygen

Figure 102. Surface Currents Subtab for Case 1 of the "CHAWS" Example

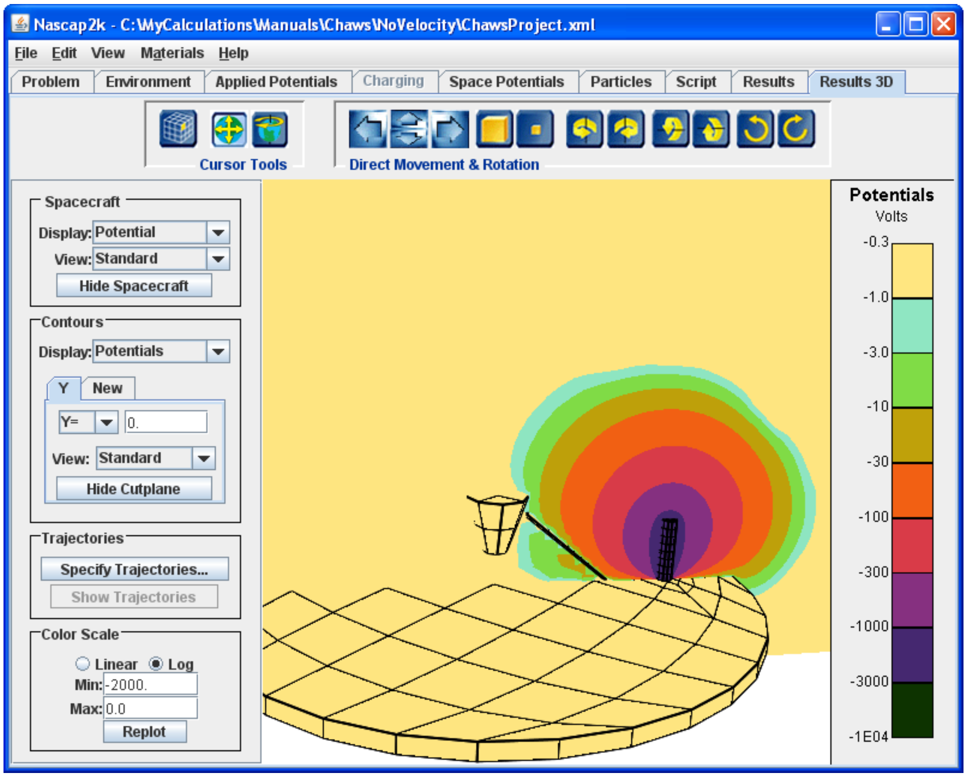


File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D
Run Script Edit Script

	Value
C Read_Object	
A FileName	ChawsObject.xml
C Embed_Object_in_Grid	
A InputFileName	Chaws_n2kdyn_in.txt
A OutputFileName	Chaws_n2kdyn_out.txt
C Potentials_in_Space	
A InputFileName	Chaws_potent_0_in.txt
A OutputFileName	Chaws_potent_0_out.txt
A Iteration	0
C Create_Particles	
A InputFileName	Chaws_partgen_Oxygen_0_in.txt
A OutputFileName	Chaws_partgen_Oxygen_0_out.txt
A Track_mode	Surface_Currents
A Creation_mode	Regular
A Species	Oxygen
A ExecuteEvery	1
C Track_Particles	
A InputFileName	Chaws_tracker_traj_0_in.txt
A OutputFileName	Chaws_tracker_traj_0_out.txt
A Iteration	0
A Track_mode	Surface_Currents
A Update_Time	No
A ElectronsOnly	No
A ExecuteEvery	1

☑ Automatically overwrite files

Figure 103. Script for Case 1 of the "CHAWS" Example



Nascap2k - C:\MyCalculations\Manuals\Chaws\NoVelocity\ChawsProject.xml

File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D
Cursor Tools
Direct Movement & Rotation

Spacecraft
Display: Potential
View: Standard

Contours
Display: Potentials
Y New
Y= 0.
View: Standard

Hide Cutplane
Trajectories
Specify Trajectories...
Show Trajectories

Color Scale
○ Linear ● Log
Min: -2000.
Max: 0.0

Replot
Potentials
Volts
-0.3
-1.0
-3.0
-10
-30
-100
-300
-1000
-3000
-1E04

Figure 104. Potential Profile for Case 1 of the "CHAWS" Example

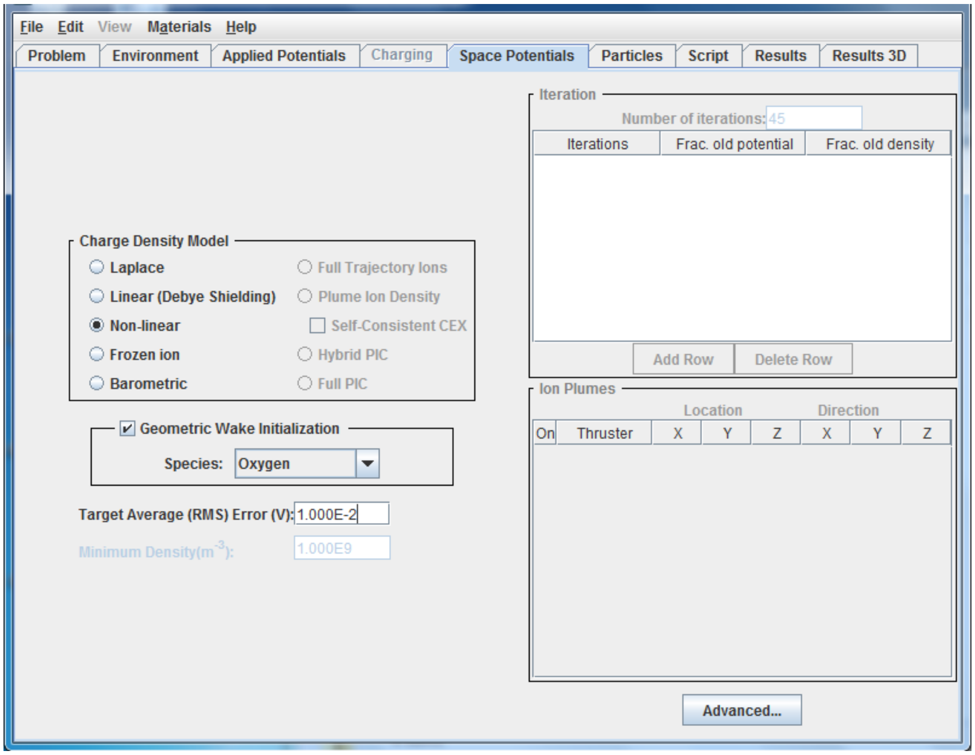
20.3.2 Case 2: Current Collection in the Wake using Analytic Space Charge Formulation.

For this case, create a new project by either making a copy of the existing CHAWS folder with a new name or beginning one from scratch. In this second case we apply the non-zero spacecraft velocity by changing the Z-component on the **Environment** tab from zero to 7800 (Vz = 7800 under the "Spacecraft Velocity" section). Notice that the Z-direction is normal to the WSF disk. The other two velocity components remain zero. The specifications on the **Applied Potentials** tab remain the same as in Case 1.

The **Space Potentials** tab is shown in Figure 105. Note that "Geometric Wake Initialization," which computes the wake of the (uncharged) spacecraft (i.e., wake is filled due to the thermal motion of ions), is checked. Because oxygen is the only ion species specified on the **Environment** tab, it is the only option under "Geometric Wake Initialization" (and therefore the mass used in this calculation is the mass of oxygen ions). All parameters on the **Advanced Potential Solver Parameters** dialog box remain unchanged from Case 1 except the value of "Maxitc," which has to be increased from 50 to 75 in order to achieve adequate convergence (Figure 106). The usage of "Maxitc" is described in Section 14.1.

Figure 107 shows the **Surface Currents** subtab of the **Particles** tab. The "Boundary" option is used for the initial particle distribution, which generates a thermal distribution of O^+ ions at the problem boundaries. The sequence representing how the undisplaced Maxwellian distribution is divided in this example is shown on the **Advanced Particle Parameters** dialog box (Figure 108) under "Fraction of Distribution." (See Section 15.3.) Make sure all parameters match those shown in this figure.

Once all of the values have been set, go to the **Script** tab and build and run the script.



Charge Density Model

- ○ Laplace
- ○ Linear (Debye Shielding)
- ● Non-linear
- ○ Frozen ion
- ○ Barometric
- ○ Full Trajectory Ions
- ○ Plume Ion Density
- □ Self-Consistent CEX
- ○ Hybrid PIC
- ○ Full PIC

☑ Geometric Wake Initialization

Species: Oxygen

Target Average (RMS) Error (V): 1.000E-2

Minimum Density(m^{-3}): 1.000E9

Iteration

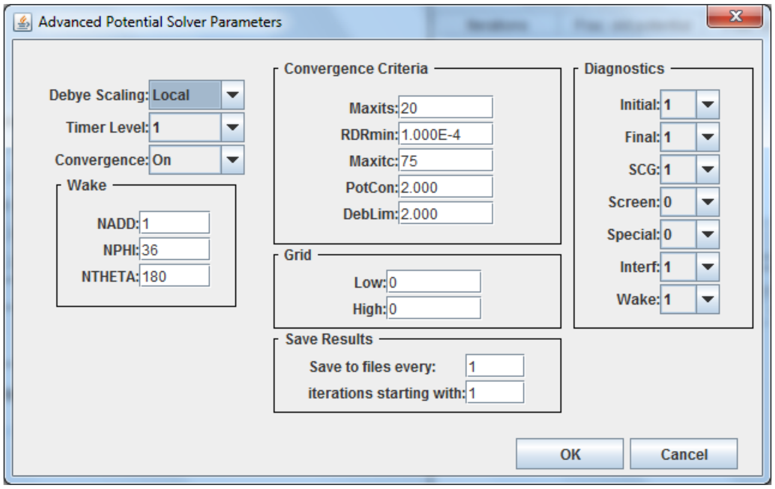
Number of iterations: 45

Iterations	Frac. old potential	Frac. old density

Ion Plumes

		Location			Direction		
On	Thruster	X	Y	Z	X	Y	Z

Figure 105. Space Potentials Tab for Case 2 of the “CHAWS” Example



Debye Scaling: Local

Timer Level: 1

Convergence: On

Wake

NADD: 1

NPHI: 36

NTHETA: 180

Convergence Criteria

Maxits: 20

RDRmin: 1.000E-4

Maxitc: 75

PotCon: 2.000

DebLim: 2.000

Grid

Low: 0

High: 0

Save Results

Save to files every: 1

iterations starting with: 1

Diagnostics

Initial: 1

Final: 1

SCG: 1

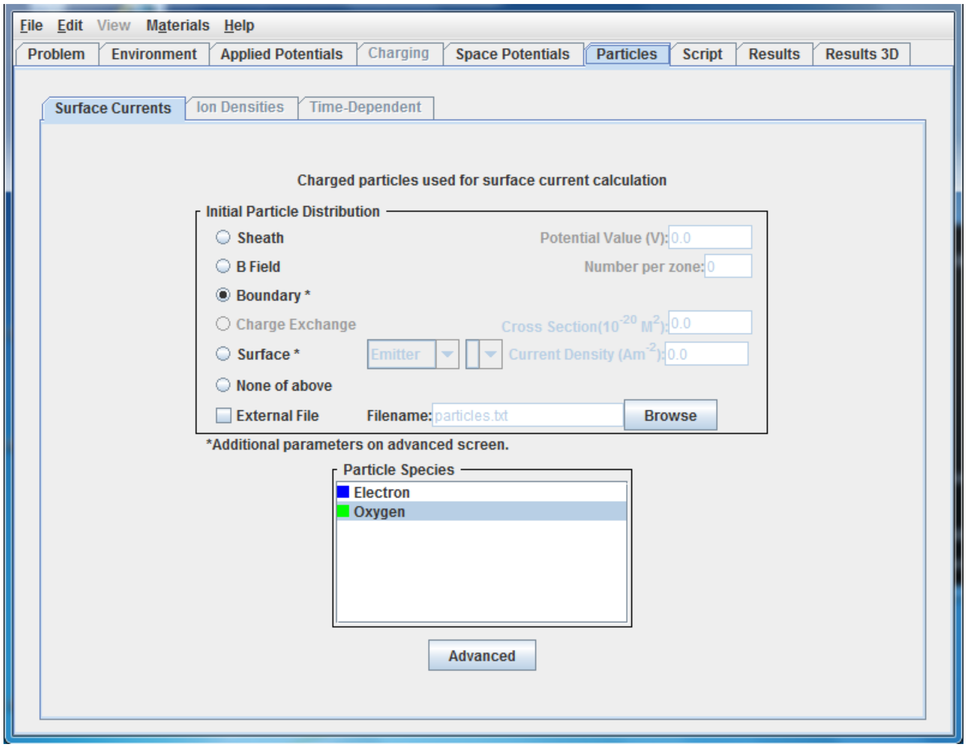
Screen: 0

Special: 0

Interf: 1

Wake: 1

Figure 106. Advanced Potential Solver Parameters Dialog Box for Case 2 of the “CHAWS” Example



Charged particles used for surface current calculation

Initial Particle Distribution

○ Sheath Potential Value (V): 0.0

○ B Field Number per zone: 0

● Boundary *

○ Charge Exchange Cross Section(10^{-20} M^2): 0.0

○ Surface * Emitter Current Density (Am^{-2}): 0.0

○ None of above

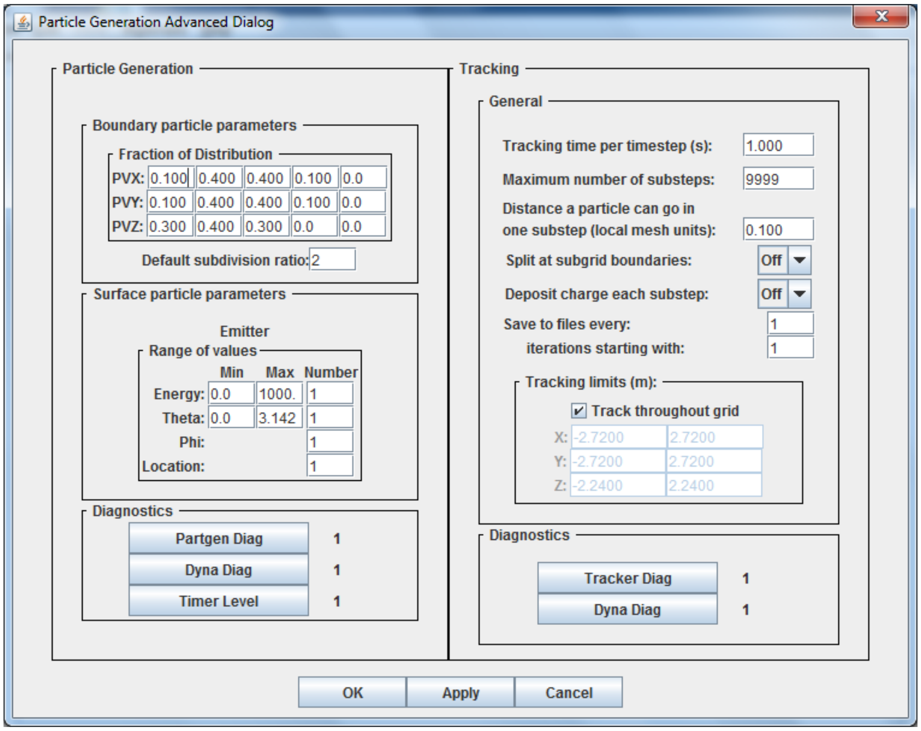
□ External File Filename: particles.txt

*Additional parameters on advanced screen.

Particle Species

- 🟦 Electron
- 🟩 Oxygen

Figure 107. Surface Currents Subtab for Case 2 of the “CHAWS” Example



Particle Generation

Boundary particle parameters

Fraction of Distribution

PVX:	0.100	0.400	0.400	0.100	0.0
PVY:	0.100	0.400	0.400	0.100	0.0
PVZ:	0.300	0.400	0.300	0.0	0.0

Default subdivision ratio: 2

Surface particle parameters

Emitter

Range of values

	Min	Max	Number
Energy:	0.0	1000.	1
Theta:	0.0	3.142	1
Phi:			1
Location:			1

Diagnostics

Partgen Diag 1

Dyna Diag 1

Timer Level 1

Tracking

General

Tracking time per timestep (s): 1.000

Maximum number of substeps: 9999

Distance a particle can go in one substep (local mesh units): 0.100

Split at subgrid boundaries: Off

Deposit charge each substep: Off

Save to files every: 1

iterations starting with: 1

Tracking limits (m):

☑ Track throughout grid

X:	-2.7200	2.7200
Y:	-2.7200	2.7200
Z:	-2.2400	2.2400

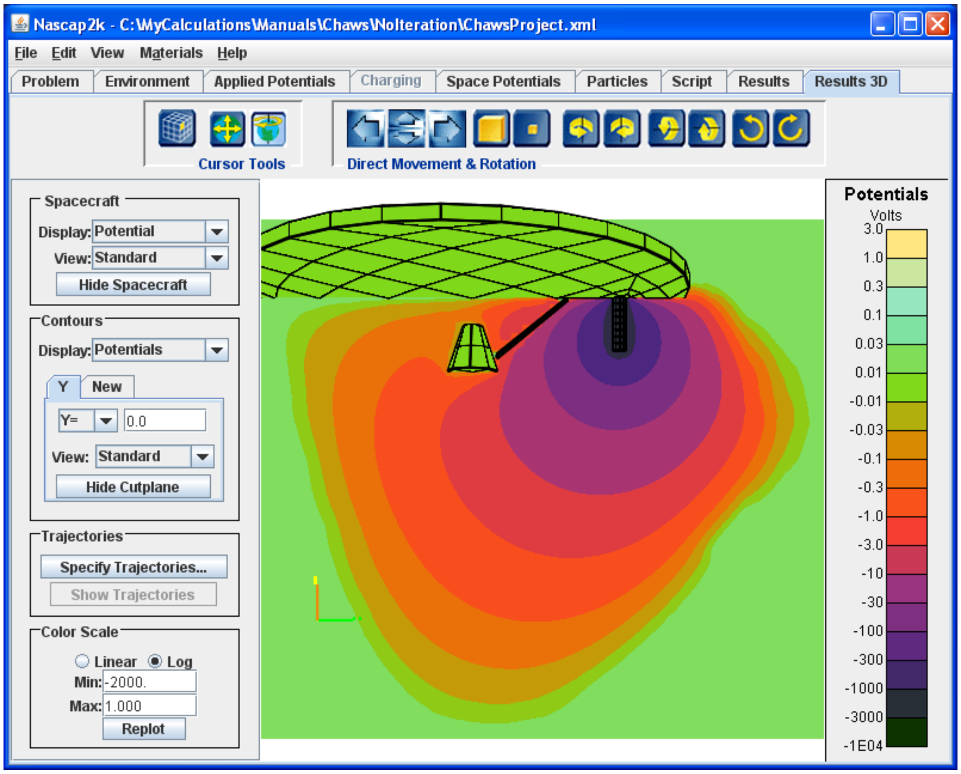
Diagnostics

Tracker Diag 1

Dyna Diag 1

Figure 108. Advanced Particle Parameters Dialog Box for Case 2 of the “CHAWS” Example

Figure 109 depicts the potential distribution in the wake of the WSF. To display (or hide) the cut plane click on the “Show (Hide) Cut Plane” button. As the probe is in the wake for this calculation, the plasma density behind WSF is lower and provides less shielding of the probe potential. The probe-induced potential extends far enough beyond the edge of the WSF, into the flow of ions, to deflect some of these ions into the wake where they can be collected by the probe. Figure 110 shows the specified distribution of particles around the boundary (ram region) and the manner by which they are collected by the probe in the wake region. To see the trajectories, click the “Specify Trajectories” button. The **Particle Visualization** dialog box appears. Select “Boundary” as the “Initial Particle Distribution for Trajectories” as shown in Figure 111. The distribution of initial directions is set on the **Advanced Particles Parameters** dialog box, which is accessed by clicking the “Advanced” button. Set the values shown in Figure 112 and then return to the **Particle Visualization** dialog box after applying the changes. Finally, click the “OK” button to start the calculation. (After trajectories have been specified, it is only necessary to click on the “Show Trajectories” button to view trajectories.) The collected ions are attracted toward the probe tip, with a large portion of them striking the tip at an oblique angle. Those that miss the tip strike the inboard side of the probe while still moving toward the WSF. Very few ions hit the outboard side of the probe. The current (see **CHAWS_tracker_traj_0.out.txt**) to the probe (material: Kapton, conductor: 2) is 330 μA, considerably greater than the 91 μA calculated for the stationary case.

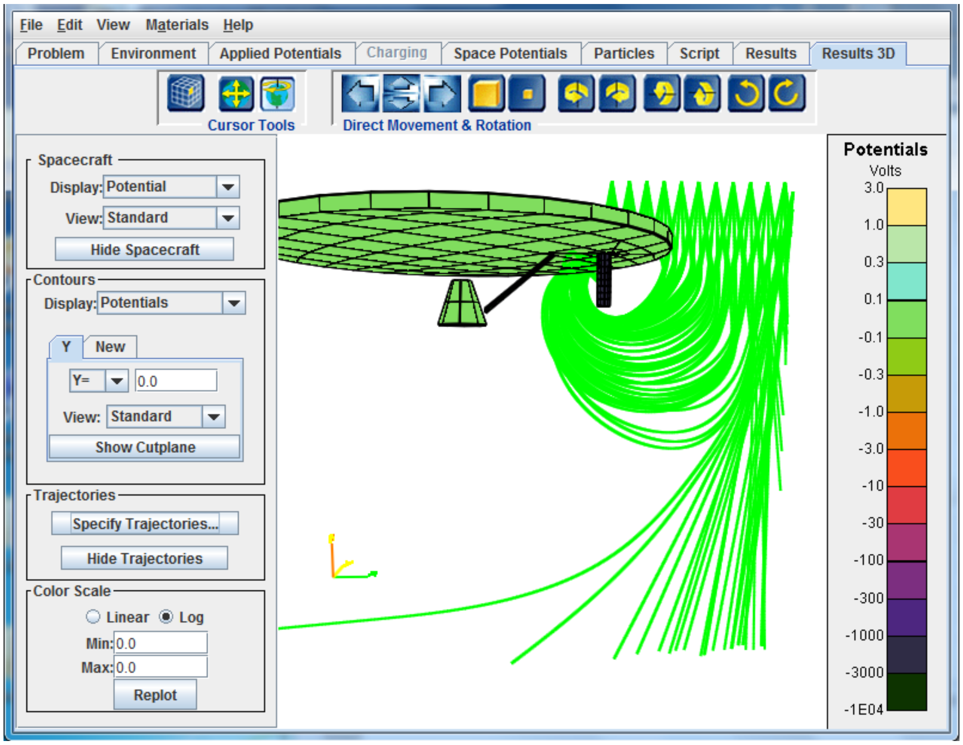


Spacecraft Display: Potential
View: Standard

Contours Display: Potentials
Y= 0.0
View: Standard

○ Linear ● Log
Min: -2000.
Max: 1.000

Figure 109. Potential Distribution for Case 2 of the “CHAWS” Example



Spacecraft

Display: Potential

View: Standard

Contours

Display: Potentials

Y New

Y= 0.0

View: Standard

Trajectories

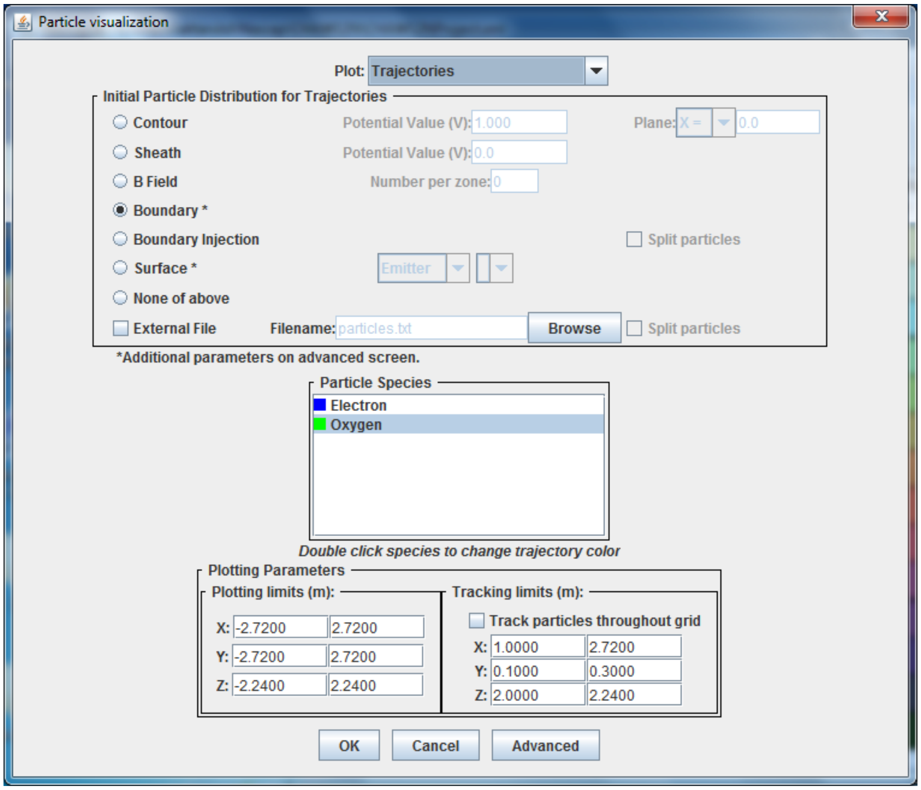
Color Scale

○ Linear ● Log

Min: 0.0

Max: 0.0

Figure 110. Ion Trajectories for Case 2 of the "CHAWS" Example



Plot: Trajectories

Initial Particle Distribution for Trajectories

○ Contour Potential Value (V): 1.000 Plane: X = 0.0

○ Sheath Potential Value (V): 0.0

○ B Field Number per zone: 0

● Boundary *

○ Boundary Injection □ Split particles

○ Surface * Emitter

○ None of above

□ External File Filename: particles.txt □ Split particles

*Additional parameters on advanced screen.

Particle Species

🟦 Electron

🟩 Oxygen

Double click species to change trajectory color

Plotting Parameters

Plotting limits (m):		
X:	-2.7200	2.7200
Y:	-2.7200	2.7200
Z:	-2.2400	2.2400

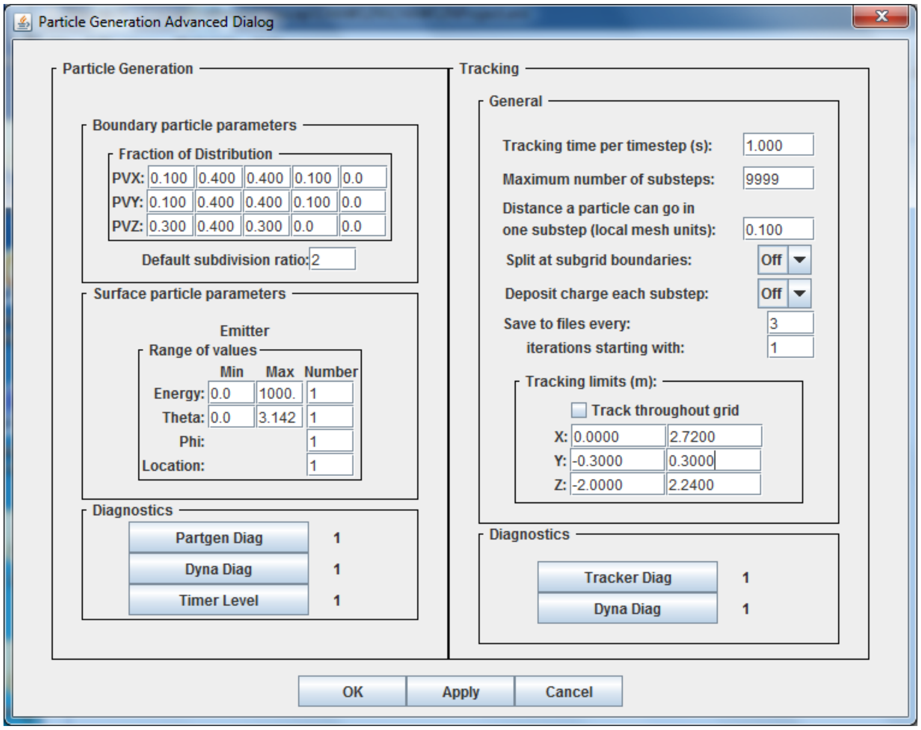
Tracking limits (m):

□ Track particles throughout grid

X:	1.0000	2.7200
Y:	0.1000	0.3000
Z:	2.0000	2.2400

Figure 111. Particle Parameters Dialog Box for Graphical Display of Trajectories for "CHAWS" Example

Approved for public release; distribution is unlimited.



Particle Generation

Boundary particle parameters

Fraction of Distribution

PVX:	0.100	0.400	0.400	0.100	0.0
PVY:	0.100	0.400	0.400	0.100	0.0
PVZ:	0.300	0.400	0.300	0.0	0.0

Default subdivision ratio: 2

Surface particle parameters

Emitter

Range of values

	Min	Max	Number
Energy:	0.0	1000.	1
Theta:	0.0	3.142	1
Phi:			1
Location:			1

Diagnostics

Partgen Diag 1

Dyna Diag 1

Timer Level 1

Tracking

General

Tracking time per timestep (s): 1.000

Maximum number of substeps: 9999

Distance a particle can go in one substep (local mesh units): 0.100

Split at subgrid boundaries: Off

Deposit charge each substep: Off

Save to files every: 3

iterations starting with: 1

Tracking limits (m):

□ Track throughout grid

X:	0.0000	2.7200
Y:	-0.3000	0.3000
Z:	-2.0000	2.2400

Diagnostics

Tracker Diag 1

Dyna Diag 1

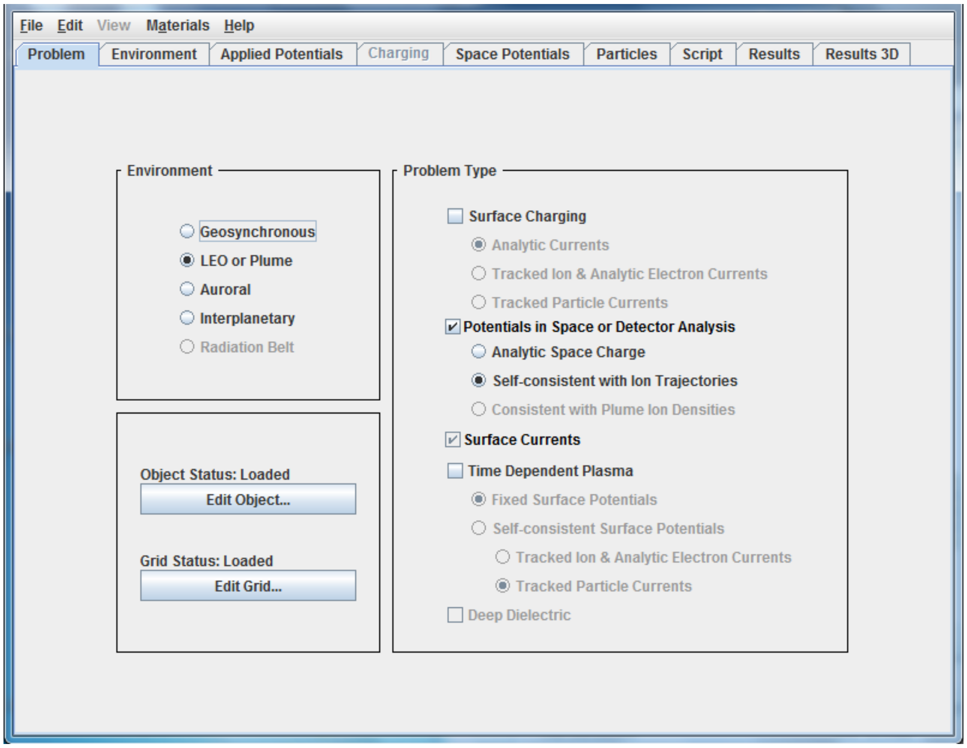
Figure 112. Advanced Particle Parameters Dialog Box for Graphical Display of Trajectories for "CHAWS" Example

20.3.3 Case 3: Current Collection in the Wake using "Self-Consistent with Ion Trajectories."

Here we repeat Case 2 but this time we will derive ion charge densities from ion trajectory calculations rather than from the analytic formulation. This requires iteratively calculating the space potentials and ion trajectories until self-consistency is attained. Recall that only positively charged species are modeled with this approach. On the **Problem** tab (Figure 113), "Self-consistent with Ion Trajectories" is checked instead of "Analytic Space Charge" model. This choice disables all charge density models on the **Space Potentials** tab except "Full Trajectory Ions." The appropriate value for the minimum density is 100 times smaller than the ambient plasma density, 10^9 m^{-3}. The calculation of the plasma density variation due to the spacecraft motion is only done in a "NEW" potential run, i.e., the zeroth iteration. As shown in Figure 114, we first perform 10 iterations, using 30% of the previously calculated potential for each iteration, and 70% of the previously calculated plasma density for each iteration except the first. The first step (zeroth iteration) is the same as Case 2.

Particles are generated using "Boundary" (Section 15.1) on the **Ion Densities** subtab of the **Particles** tab as shown in Figure 115. Notice the PVX, PVY, and PVZ divisions on the **Advanced Particle Parameters** dialog box in Figure 116.

Potential profiles and particle trajectories are shown in Figure 117 and Figure 118, respectively. The tracking boundaries and other parameters for the **Particle Parameters** dialog box are the same as Case 2 (Figure 111). A comparison between Figure 109 and Figure 117 shows differences in the potential distribution between Cases 2 and 3. The value of current collected by the probe is 120 µA, a factor of three less than in Case 2. The reason for this current reduction is additional screening of the probe potential by the space charge of the collected ions. Ten additional iterations change the current collected by the probe by less than 2%.



Environment

○ Geosynchronous
● LEO or Plume
○ Auroral
○ Interplanetary
○ Radiation Belt

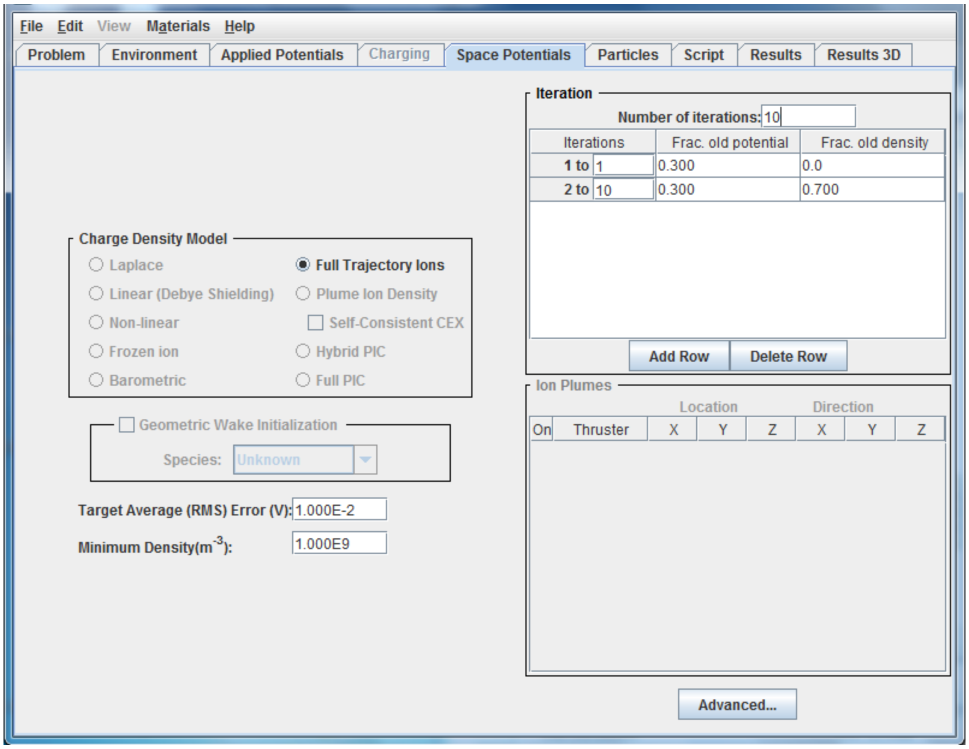
Object Status: Loaded

Grid Status: Loaded

Problem Type

□ Surface Charging
● Analytic Currents
○ Tracked Ion & Analytic Electron Currents
○ Tracked Particle Currents
☑ Potentials in Space or Detector Analysis
○ Analytic Space Charge
● Self-consistent with Ion Trajectories
○ Consistent with Plume Ion Densities
☑ Surface Currents
□ Time Dependent Plasma
● Fixed Surface Potentials
○ Self-consistent Surface Potentials
○ Tracked Ion & Analytic Electron Currents
● Tracked Particle Currents
□ Deep Dielectric

Figure 113. Problem Tab for Case 3 of the “CHAWS” Example



Iteration

Number of iterations: 10

	Iterations	Frac. old potential	Frac. old density
1 to	1	0.300	0.0
2 to	10	0.300	0.700

Charge Density Model

- ○ Laplace
- ○ Linear (Debye Shielding)
- ○ Non-linear
- ○ Frozen ion
- ○ Barometric
- ● Full Trajectory Ions
- ○ Plume Ion Density
- □ Self-Consistent CEX
- ○ Hybrid PIC
- ○ Full PIC

□ Geometric Wake Initialization

Species: Unknown

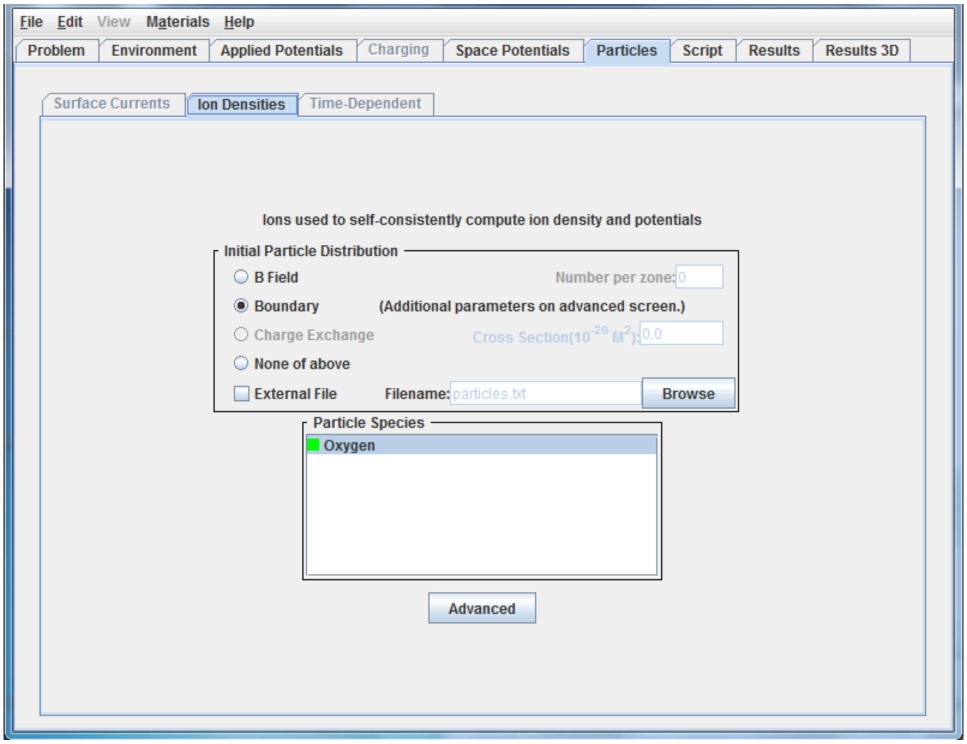
Target Average (RMS) Error (V): 1.000E-2

Minimum Density(m^{-3}): 1.000E9

Ion Plumes

		Location			Direction		
On	Thruster	X	Y	Z	X	Y	Z

Figure 114. Space Potentials Tab for Case 3 of the “CHAWS” Example



Ions used to self-consistently compute ion density and potentials

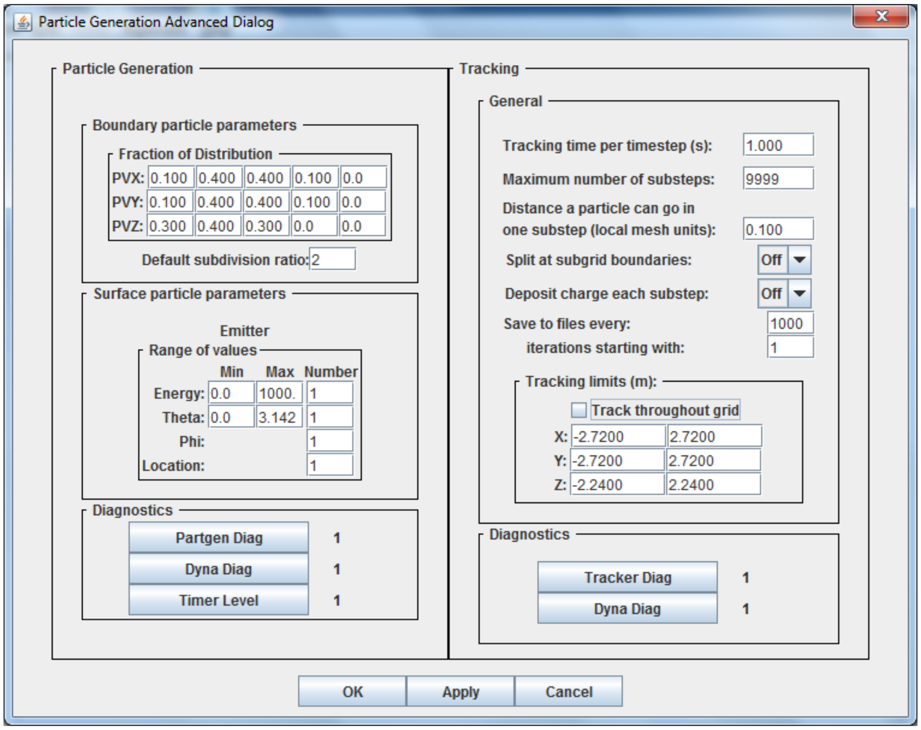
Initial Particle Distribution

- ○ B Field Number per zone: 0
- ● Boundary (Additional parameters on advanced screen.)
- ○ Charge Exchange Cross Section(10^{-20} M^2): 0.0
- ○ None of above
- □ External File Filename: particles.txt

Particle Species

🟩 Oxygen

Figure 115. Ion Densities Subtab for Case 3 of the “CHAWS” Example



Particle Generation Advanced Dialog

Particle Generation

Boundary particle parameters

Fraction of Distribution

PVX:	0.100	0.400	0.400	0.100	0.0
PVY:	0.100	0.400	0.400	0.100	0.0
PVZ:	0.300	0.400	0.300	0.0	0.0

Default subdivision ratio: 2

Surface particle parameters

Emitter

Range of values

	Min	Max	Number
Energy:	0.0	1000.	1
Theta:	0.0	3.142	1
Phi:			1
Location:			1

Diagnostics

Partgen Diag 1

Dyna Diag 1

Timer Level 1

Tracking

General

Tracking time per timestep (s): 1.000

Maximum number of substeps: 9999

Distance a particle can go in one substep (local mesh units): 0.100

Split at subgrid boundaries: Off

Deposit charge each substep: Off

Save to files every: 1000

iterations starting with: 1

Tracking limits (m):

□ Track throughout grid

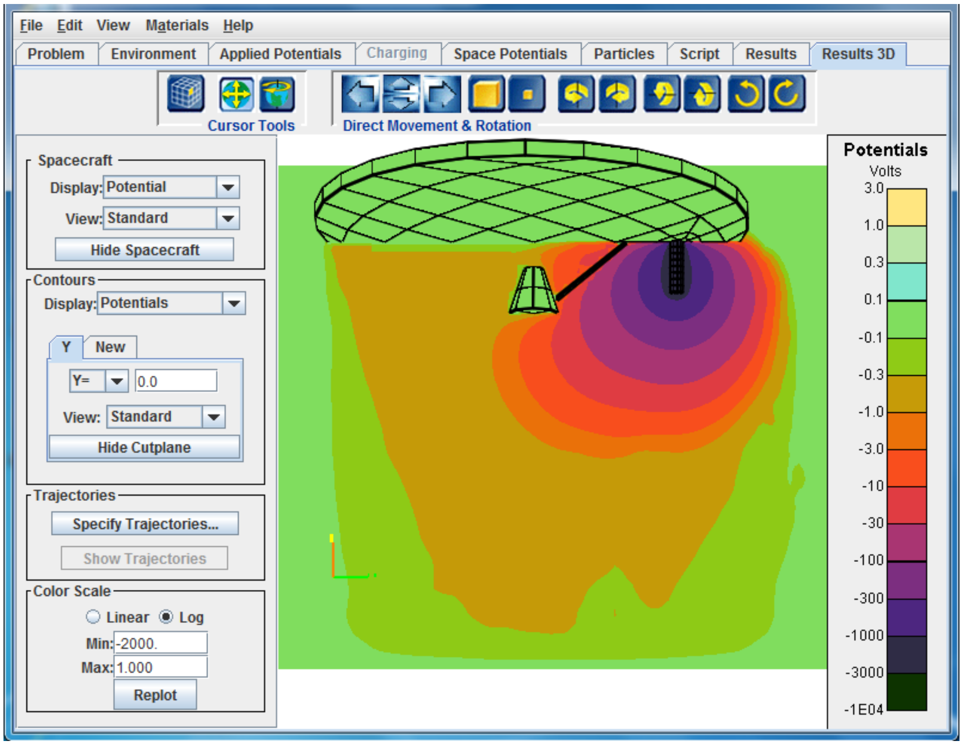
X:	-2.7200	2.7200
Y:	-2.7200	2.7200
Z:	-2.2400	2.2400

Diagnostics

Tracker Diag 1

Dyna Diag 1

Figure 116. Advanced Particle Parameters Dialog Box for Particle Generation and Tracking for Case 3 of the "CHAWS" Example



Spacecraft

Display: Potential

View: Standard

Hide Spacecraft

Contours

Display: Potentials

Y New

Y= 0.0

View: Standard

Hide Cutplane

Trajectories

Specify Trajectories...

Show Trajectories

Color Scale

○ Linear ● Log

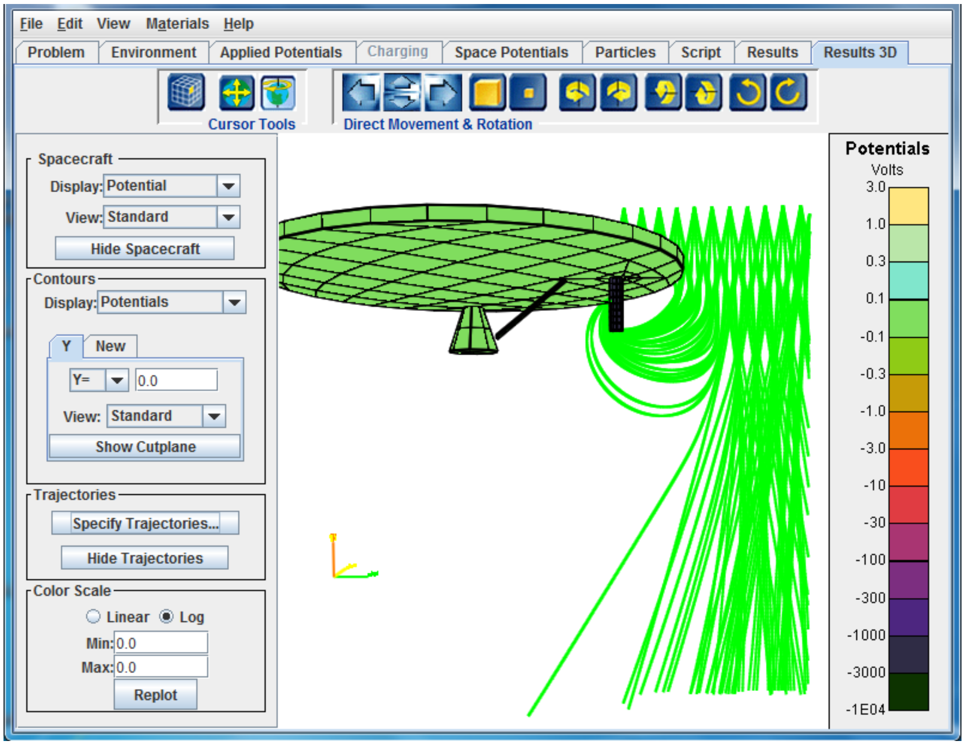
Min: -2000.

Max: 1.000

Replot

Figure 117. Potential in the Wake of WSF for Case 3 of the "CHAWS" Example

Approved for public release; distribution is unlimited.

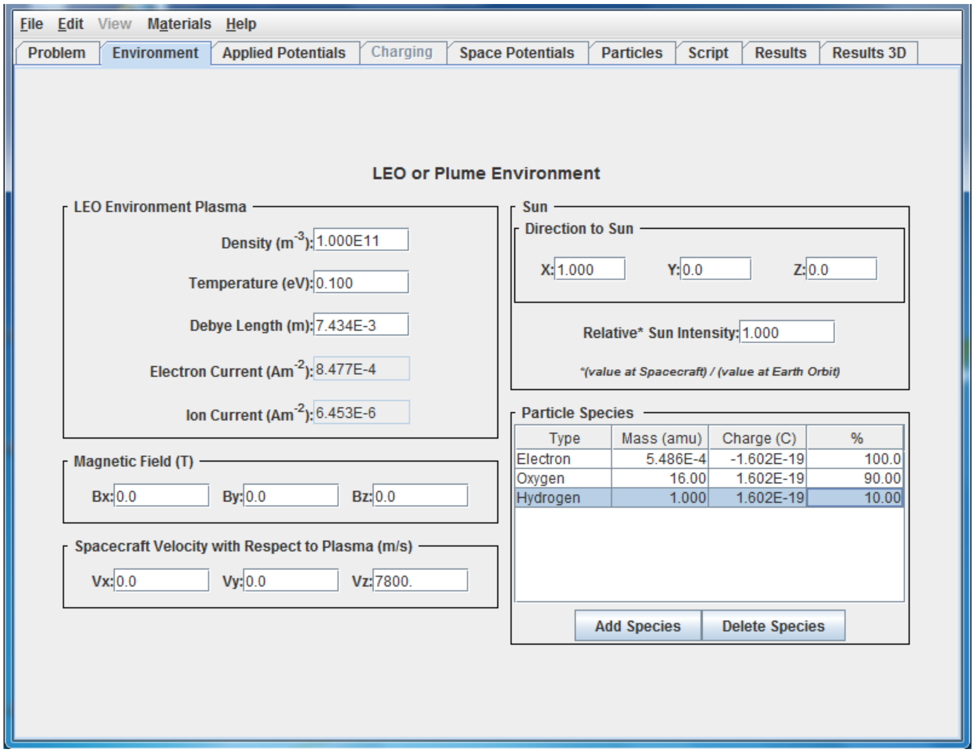


Display: Potential
View: Standard
Display: Potentials
Y= 0.0
View: Standard
○ Linear ● Log
Min: 0.0
Max: 0.0

Figure 118. Trajectories for Case 3 of the "CHAWS" Example

20.3.4 Case 4: Current Collection in the Wake using "Self-Consistent with Ion Trajectories" and 10% H^+.

All previous cases assumed the ion population consists only of O^+ ions. However, even a small concentration of faster-moving, lighter ions such as H^+ can be a significant wake-filling mechanism that can lead to enhanced current collection. In this case we repeat Case 3 by including 10% H^+ ions, as shown in Figure 119, and perform five iterations (Figure 120) beginning from the solution of Case 3. Note on Figure 120, the number of iterations refers to the total number (the initial 10 for Case 3 and 5 additional for Case 4 for a total of 15 iterations). The boundary particle parameters on the **Advanced Particle Parameters** dialog box of the **Ion Densities** subtab remain as in Case 3. Notice in Figure 121 that both ion species are highlighted. Figure 122 depicts the script for this case. First delete all commands leading up to the **Loop** command. Then, edit the loop iterations to match what is seen in Figure 122, that is request five (5) iterations, starting with number 11 (since Case 3 did the first 10).


File Edit View Materials Help
Problem | Environment | Applied Potentials | Charging | Space Potentials | Particles | Script | Results | Results 3D

LEO or Plume Environment

LEO Environment Plasma

Density (m^{-3}): 1.000E11

Temperature (eV): 0.100

Debye Length (m): 7.434E-3

Electron Current (Am^{-2}): 8.477E-4

Ion Current (Am^{-2}): 6.453E-6

Magnetic Field (T)

Bx: 0.0 By: 0.0 Bz: 0.0

Spacecraft Velocity with Respect to Plasma (m/s)

Vx: 0.0 Vy: 0.0 Vz: 7800.

Sun

Direction to Sun

X: 1.000 Y: 0.0 Z: 0.0

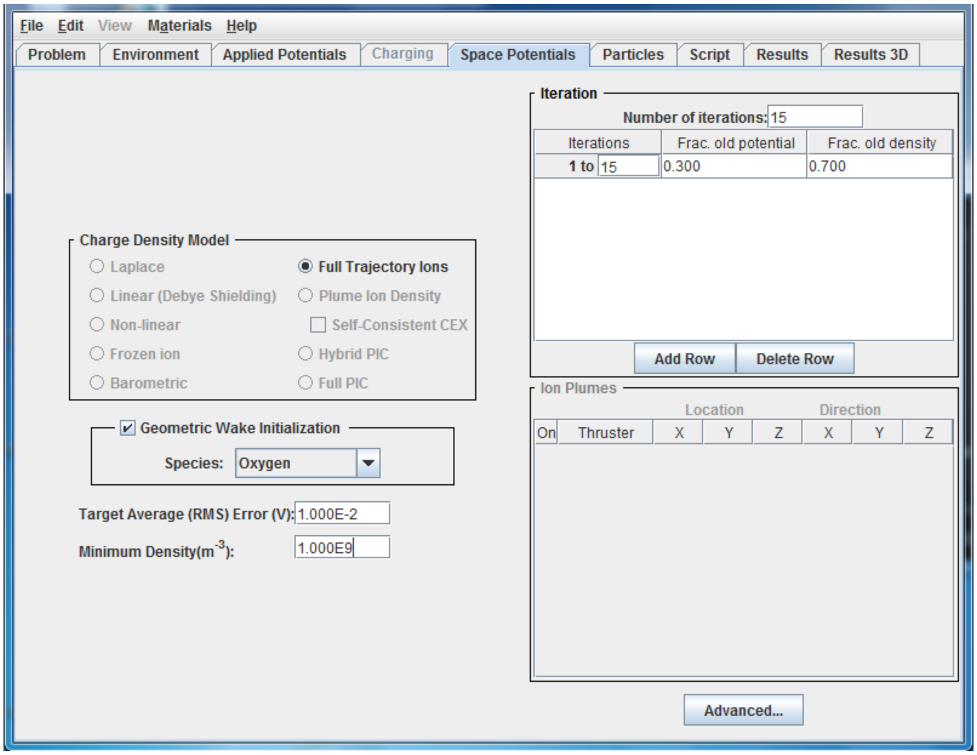
Relative* Sun Intensity: 1.000

*(value at Spacecraft) / (value at Earth Orbit)

Particle Species

Type	Mass (amu)	Charge (C)	%
Electron	5.486E-4	-1.602E-19	100.0
Oxygen	16.00	1.602E-19	90.00
Hydrogen	1.000	1.602E-19	10.00

Figure 119. Environment Tab for Case 4 of the “CHAWS” Example Showing Addition of 10% H^{+} Species


File Edit View Materials Help
Problem | Environment | Applied Potentials | Charging | Space Potentials | Particles | Script | Results | Results 3D

Charge Density Model

○ Laplace ● Full Trajectory Ions

○ Linear (Debye Shielding) ○ Plume Ion Density

○ Non-linear □ Self-Consistent CEX

○ Frozen ion ○ Hybrid PIC

○ Barometric ○ Full PIC

☑ Geometric Wake Initialization

Species: Oxygen

Target Average (RMS) Error (V): 1.000E-2

Minimum Density(m^{-3}): 1.000E9

Iteration

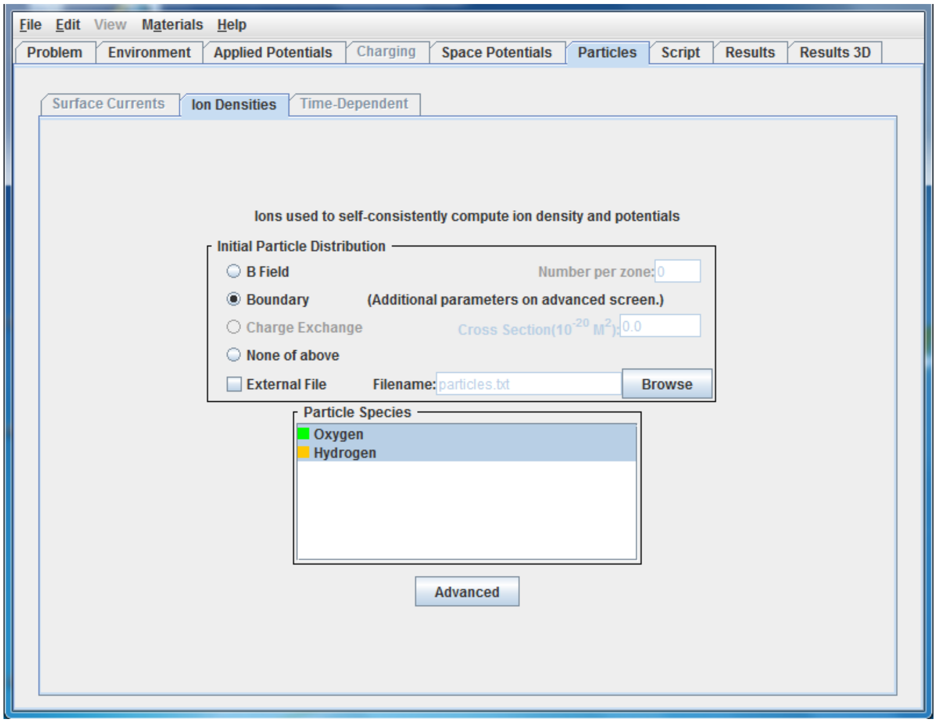
Number of iterations: 15

Iterations	Frac. old potential	Frac. old density
1 to 15	0.300	0.700

Ion Plumes

		Location			Direction		
On	Thruster	X	Y	Z	X	Y	Z

Figure 120. Space Potentials Tab for Case 4 of the “CHAWS” Example



Ions used to self-consistently compute ion density and potentials

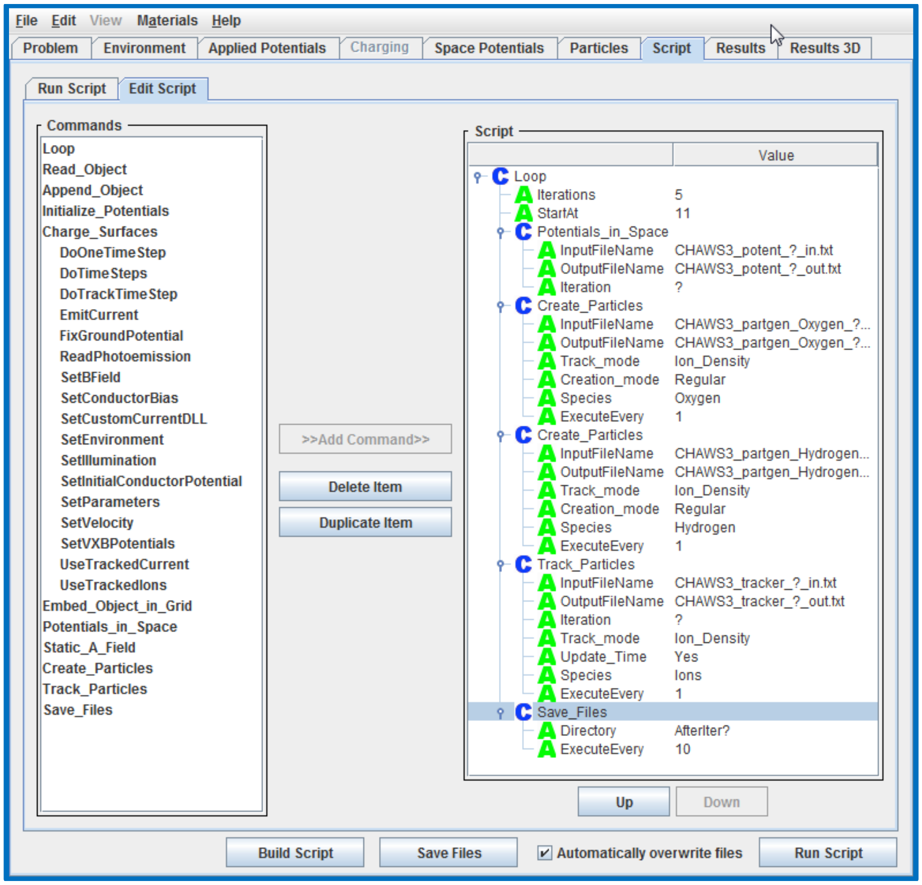
Initial Particle Distribution

- ○ B Field   Number per zone: 0
- ● Boundary   (Additional parameters on advanced screen.)
- ○ Charge Exchange   Cross Section(10^{-20} M^2): 0.0
- ○ None of above
- □ External File   Filename: particles.txt

Particle Species

- 🟩 Oxygen
- 🟨 Hydrogen

Figure 121. Ion Densities Subtab for Case 4 of the "CHAWS" Example



Commands

```
Loop
Read_Object
Append_Object
Initialize_Potentials
Charge_Surfaces
    DoOneTimeStep
    DoTimeSteps
    DoTrackTimeStep
    EmitCurrent
    FixGroundPotential
    ReadPhotoemission
    SetBField
    SetConductorBias
    SetCustomCurrentDLL
    SetEnvironment
    SetIllumination
    SetInitialConductorPotential
    SetParameters
    SetVelocity
    SetVXBPotentials
    UseTrackedCurrent
    UseTrackedIons
Embed_Object_in_Grid
Potentials_in_Space
Static_A_Field
Create_Particles
Track_Particles
Save_Files
```

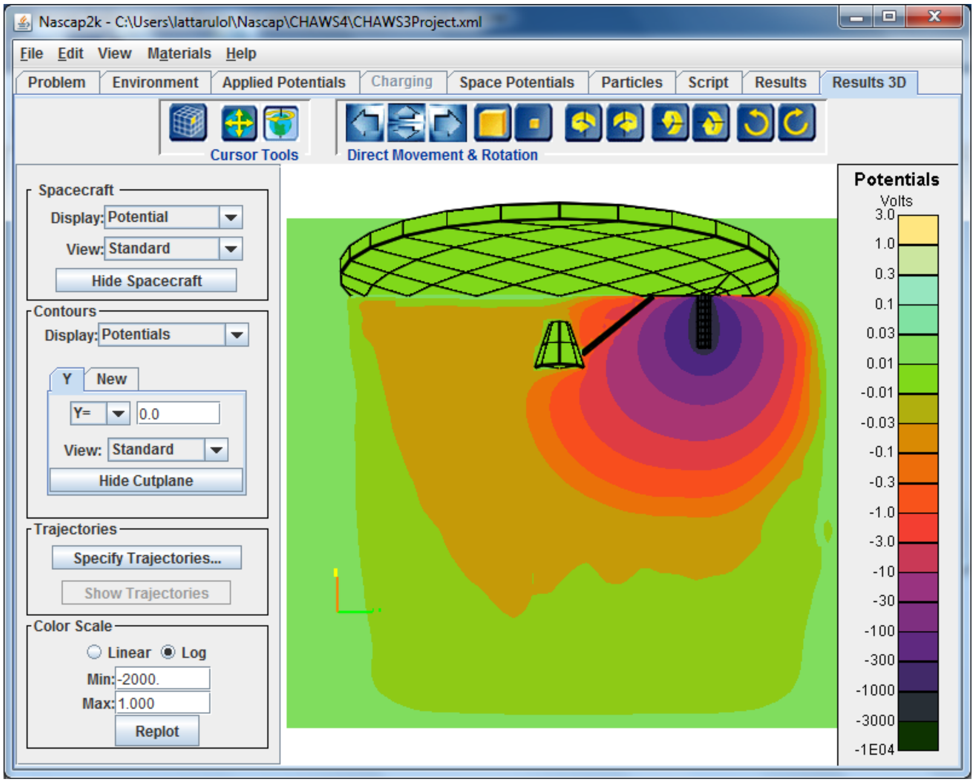
Script

```
                                    Value
C Loop
  A Iterations                      5
  A StartAt                         11
  C Potentials_in_Space
    A InputFileName                 CHAWS3_potent_?_in.txt
    A OutputFileName                CHAWS3_potent_?_out.txt
    A Iteration                     ?
  C Create_Particles
    A InputFileName                 CHAWS3_partgen_Oxygen_?...
    A OutputFileName                CHAWS3_partgen_Oxygen_?...
    A Track_mode                    Ion_Density
    A Creation_mode                 Regular
    A Species                       Oxygen
    A ExecuteEvery                  1
  C Create_Particles
    A InputFileName                 CHAWS3_partgen_Hydrogen...
    A OutputFileName                CHAWS3_partgen_Hydrogen...
    A Track_mode                    Ion_Density
    A Creation_mode                 Regular
    A Species                       Hydrogen
    A ExecuteEvery                  1
  C Track_Particles
    A InputFileName                 CHAWS3_tracker_?_in.txt
    A OutputFileName                CHAWS3_tracker_?_out.txt
    A Iteration                     ?
    A Track_mode                    Ion_Density
    A Update_Time                   Yes
    A Species                       Ions
    A ExecuteEvery                  1
  C Save_Files
    A Directory                     AfterIter?
    A ExecuteEvery                  10
```

☑ Automatically overwrite files

Figure 122. Script Used in Case 4 of the "CHAWS" Example

Figure 123 shows the potential distribution for Case 4. The potentials don't extend as far in the Z direction as the lighter weight H^+ fills in the wake. As H^+ is four times faster than O^+, the current would be expected to be about 30% higher, consistent with the computed 150 μA, about 25% more current than for a plasma of just O^+ ions. This value can be found in the tracker output file for the 15th iteration.



Nascap2k - C:\Users\lattaruloI\Nascap\CHAWS4\CHAWS3Project.xml

Spacecraft Display: Potential
View: Standard

Contours Display: Potentials
Y= 0.0
View: Standard

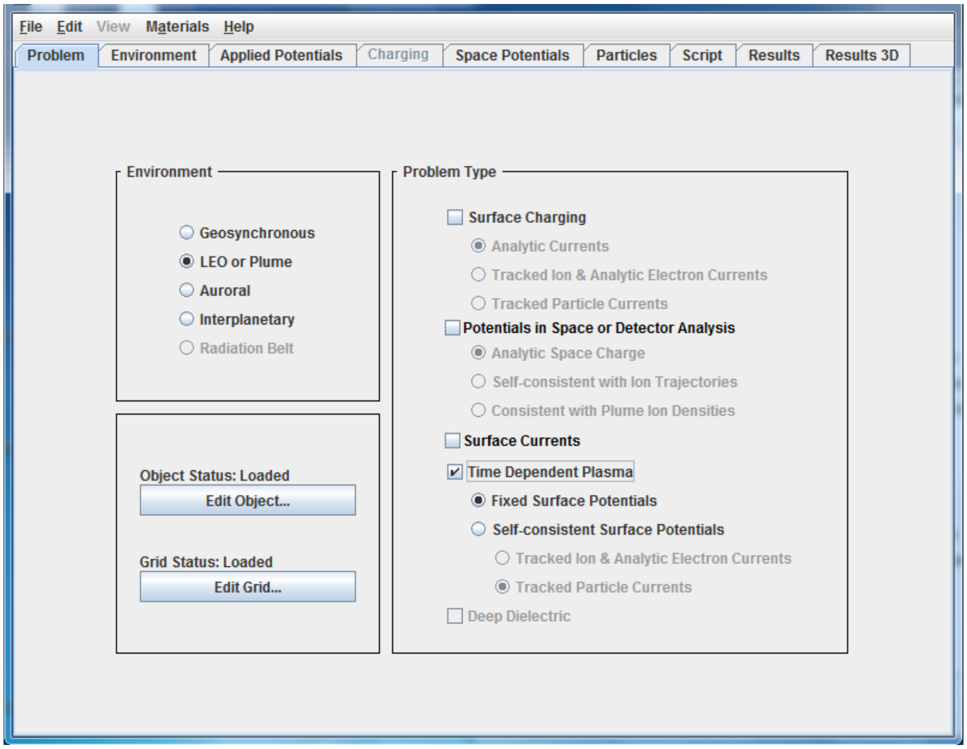
Color Scale ○ Linear ● Log
Min: -2000.
Max: 1.000

Figure 123. Potential Distribution in the WSF Wake for Case 4 of the "CHAWS" Example

21 Time Dependent Plasma (example name: "Dynamic")

21.1 Background

In this example we address the different time regimes of the electron and ion motion and compute transient sheath dynamics about a simple object. As we are interested in time dependent space potentials and surface currents resulting from an impulsively changed surface potential, the "Problem Type" is "Time Dependent Plasma" with "Fixed Surface Potentials" as shown in Figure 124.



Environment

○ Geosynchronous
● LEO or Plume
○ Auroral
○ Interplanetary
○ Radiation Belt

Object Status: Loaded

Grid Status: Loaded

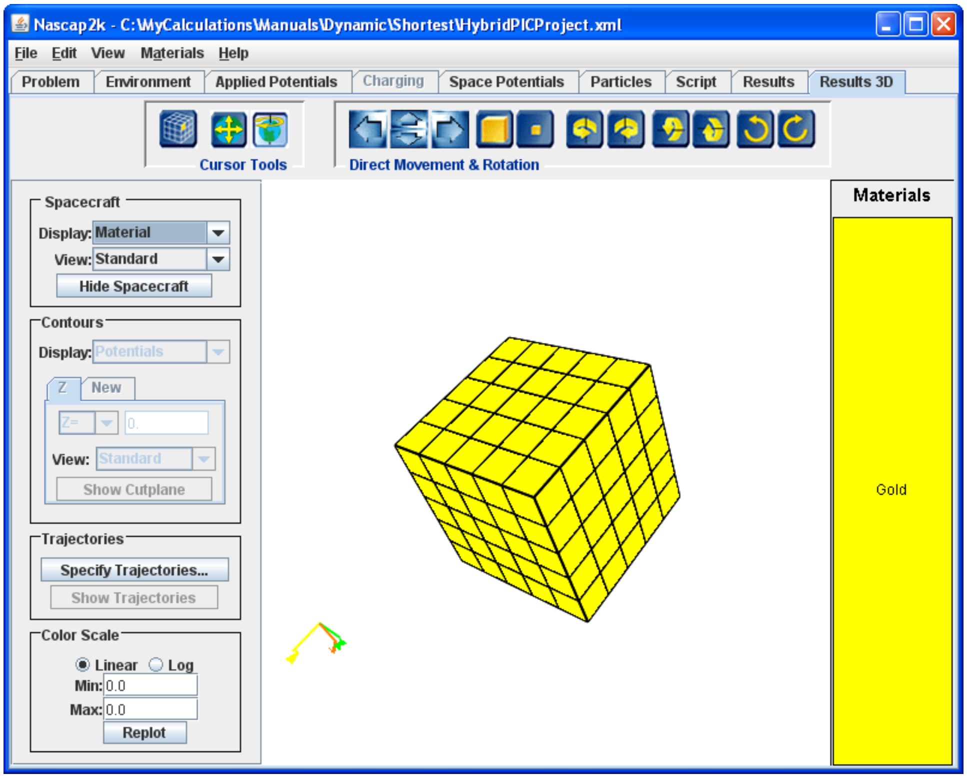
Problem Type

□ Surface Charging
● Analytic Currents
○ Tracked Ion & Analytic Electron Currents
○ Tracked Particle Currents
□ Potentials in Space or Detector Analysis
● Analytic Space Charge
○ Self-consistent with Ion Trajectories
○ Consistent with Plume Ion Densities
□ Surface Currents
☑ Time Dependent Plasma
● Fixed Surface Potentials
○ Self-consistent Surface Potentials
○ Tracked Ion & Analytic Electron Currents
● Tracked Particle Currents
□ Deep Dielectric

Figure 124. Problem Tab Showing "Time Dependent Plasma" Checked for the "Dynamic" Example

21.2 Object and Grid Definition

The object is a gold-plated cube, 20 cm in size (Figure 125). The surrounding mesh consists of a cubic parent grid 0.96 m on a side with 4 cm mesh spacing, and one child grid 0.48 m on a side with 2 cm mesh spacing (Figure 126).

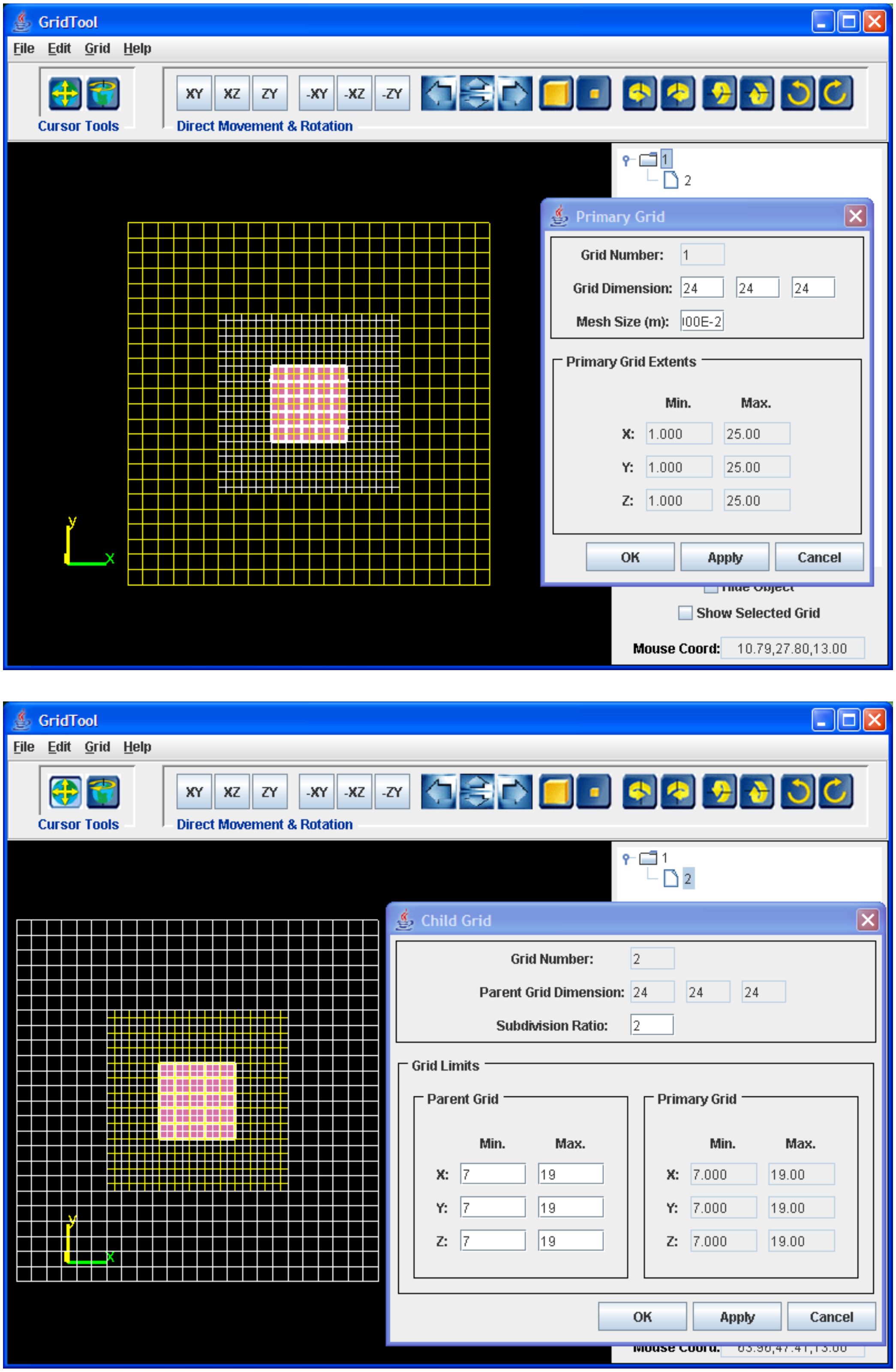


Display: Material
View: Standard

Display: Potentials
Z= 0.
View: Standard

● Linear ○ Log
Min: 0.0
Max: 0.0

Figure 125. Gold-plated Cube Used in the “Dynamic” Example



Grid Number: 1

Grid Dimension: 24 24 24

Mesh Size (m): I00E-2

Primary Grid Extents

	Min.	Max.
X:	1.000	25.00
Y:	1.000	25.00
Z:	1.000	25.00

Mouse Coord: 10.79,27.80,13.00

Grid Number: 2

Parent Grid Dimension: 24 24 24

Subdivision Ratio: 2

Grid Limits

Parent Grid

	Min.	Max.
X:	7	19
Y:	7	19
Z:	7	19

Primary Grid

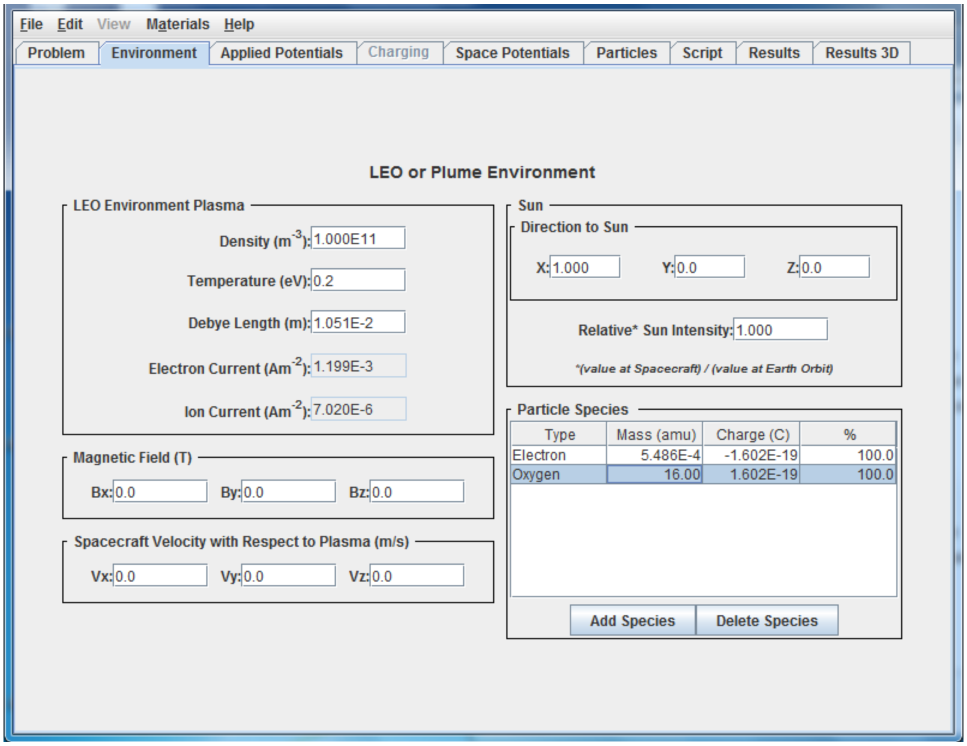
	Min.	Max.
X:	7.000	19.00
Y:	7.000	19.00
Z:	7.000	19.00

Mouse Coord: 63.96,47.41,13.00

Figure 126. Grid Definition for the “Dynamic” Example. Top: Primary Grid Definition. Bottom: Child Grid Definition

21.3 Dynamic Calculations

The calculations in this example are made assuming a moderately dense low Earth orbit plasma (10^{11} m^{-3}, 0.2 eV) and no magnetic field (Figure 127). Under these conditions the Debye length is approximately 1 cm. The electric potential of the current-collecting conductor is impulsively changed from 0 V to -100 V at time zero (Figure 128).



LEO or Plume Environment

LEO Environment Plasma

Density (m^{-3}): 1.000E11

Temperature (eV): 0.2

Debye Length (m): 1.051E-2

Electron Current (Am^{-2}): 1.199E-3

Ion Current (Am^{-2}): 7.020E-6

Magnetic Field (T)

Bx: 0.0 By: 0.0 Bz: 0.0

Spacecraft Velocity with Respect to Plasma (m/s)

Vx: 0.0 Vy: 0.0 Vz: 0.0

Sun

Direction to Sun

X: 1.000 Y: 0.0 Z: 0.0

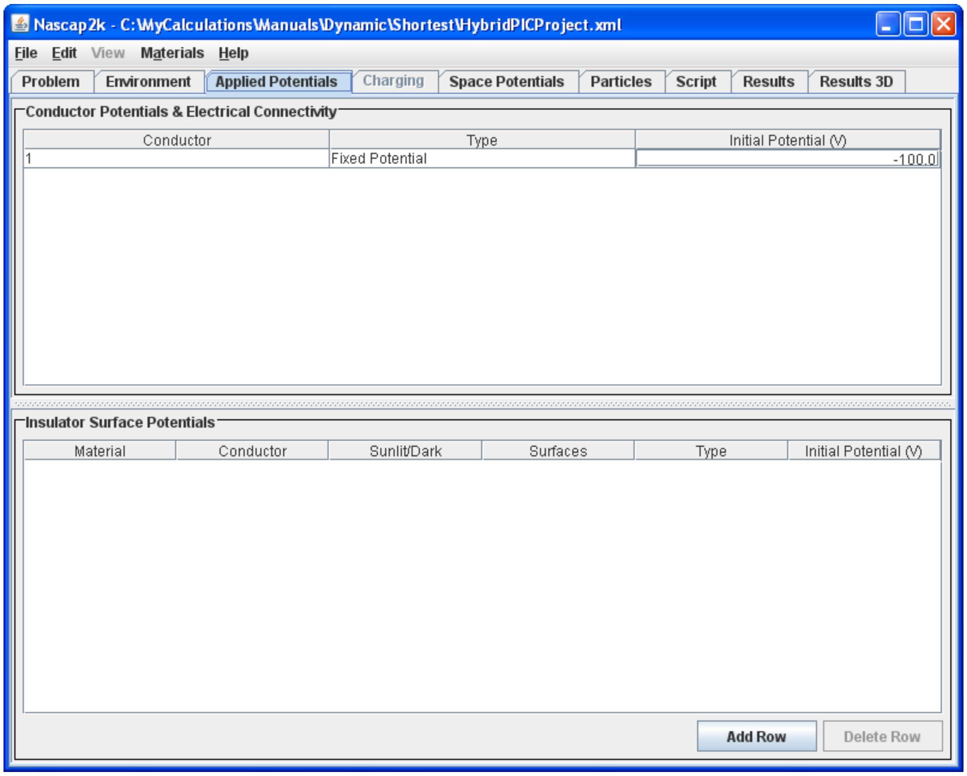
Relative* Sun Intensity: 1.000

*(value at Spacecraft) / (value at Earth Orbit)

Particle Species

Type	Mass (amu)	Charge (C)	%
Electron	5.486E-4	-1.602E-19	100.0
Oxygen	16.00	1.602E-19	100.0

Figure 127. Environment Tab for the "Dynamic" Example



Nascap2k - C:\MyCalculations\Manuals\Dynamic\Shortest\HybridPICProject.xml

Conductor Potentials & Electrical Connectivity

Conductor	Type	Initial Potential (V)
1	Fixed Potential	-100.0

Insulator Surface Potentials

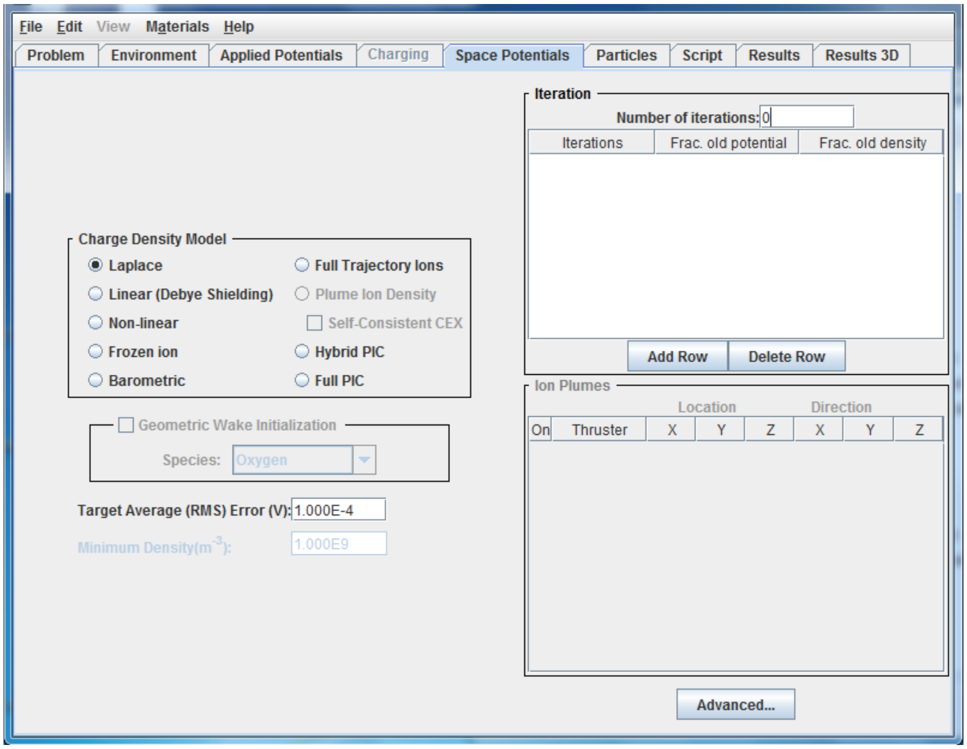
Material	Conductor	Sunlit/Dark	Surfaces	Type	Initial Potential (V)

Figure 128. Applied Potentials Tab for the “Dynamic” Example

21.3.1 Case 1: Short Time-scales for Both Species.

Create a folder for this example and copy in the object and grid files found in the **Example Problems/Dynamic** folder. You can examine the object and grid and check the **Environment** and **Applied Potentials** tabs to see that they correspond to those shown in Figure 127 and Figure 128.

For time scales in the order of nanoseconds, both electrons and ions move distances that are much less than a Debye length and may therefore be assumed to be motionless. In this time regime the plasma remains quasi-neutral, and we can therefore assume that space potentials are “Laplacian,” which is specified on the **Space Potentials** tab (Figure 129). Make sure the number of iterations is zero (0). The potential distribution around the object is shown in Figure 130. Note the monopole boundary conditions.



Charge Density Model

● Laplace
○ Linear (Debye Shielding)
○ Non-linear
○ Frozen ion
○ Barometric
○ Full Trajectory Ions
○ Plume Ion Density
□ Self-Consistent CEX
○ Hybrid PIC
○ Full PIC

□ Geometric Wake Initialization

Species: Oxygen

Target Average (RMS) Error (V): 1.000E-4

Minimum Density(m^{-3}): 1.000E9

Iteration

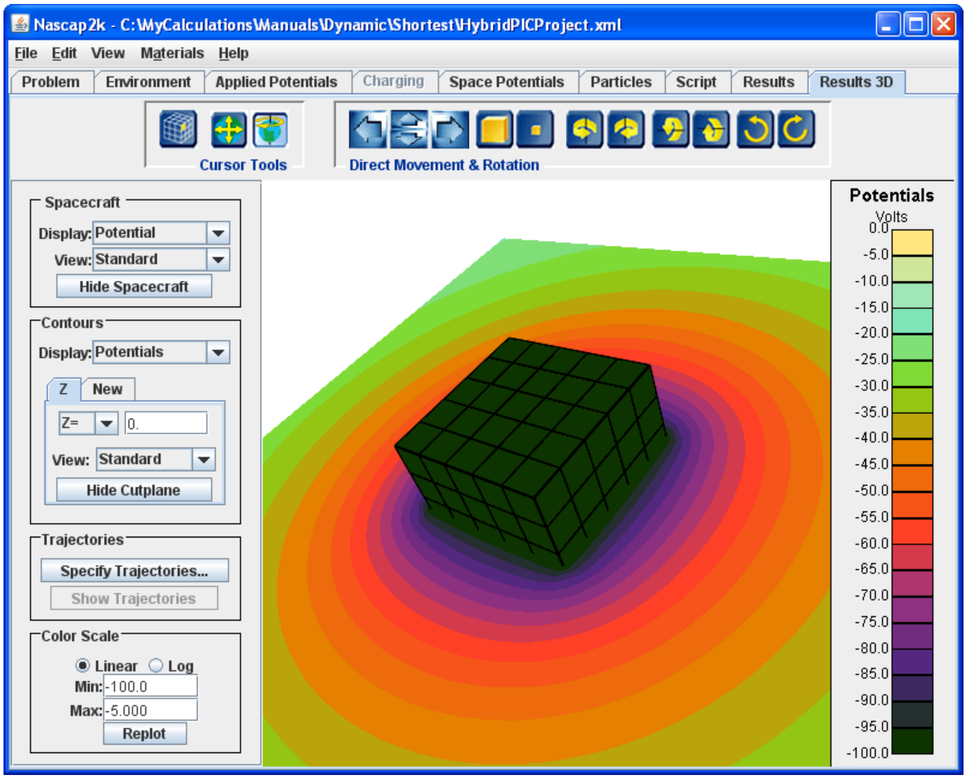
Number of iterations: 0

Iterations	Frac. old potential	Frac. old density

Ion Plumes

		Location			Direction		
On	Thruster	X	Y	Z	X	Y	Z

Figure 129. Space Potentials Tab for Case 1 of the “Dynamic” Problem



Spacecraft

Display: Potential

View: Standard

Contours

Display: Potentials

Z= 0.

View: Standard

Trajectories

Color Scale

● Linear ○ Log

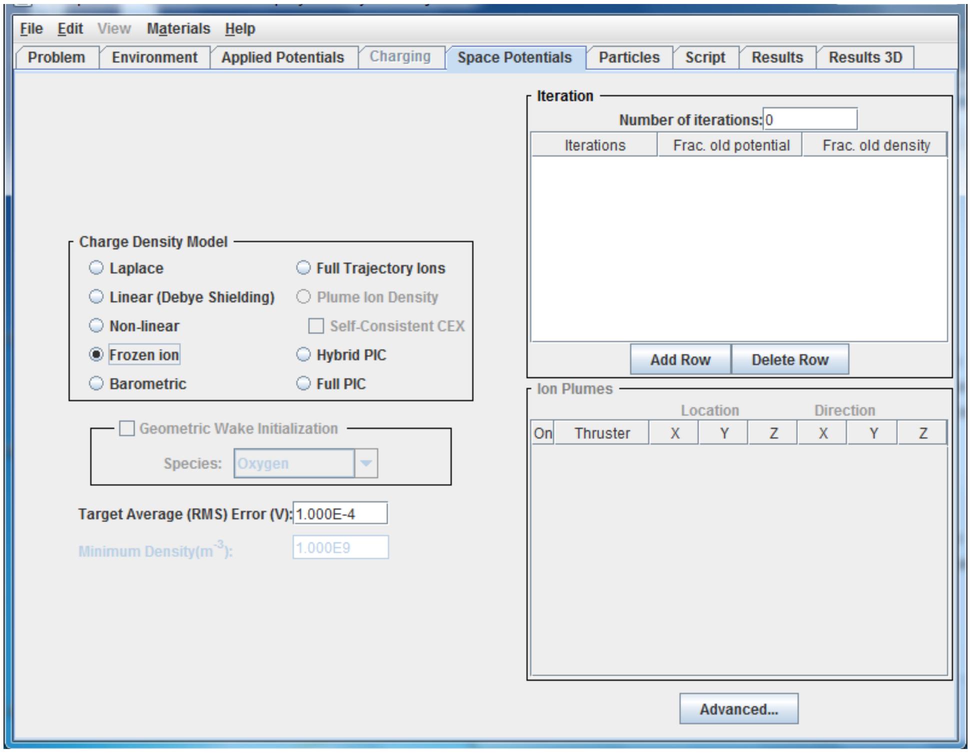
Min: -100.0

Max: -5.000

Figure 130. Results 3D Tab Showing Laplacian Space Potential Distribution

21.3.2 Case 2: Short Time-scale for Ions, Equilibrium (Barometric) Electrons.

On a microsecond time-scale, electrons travel a distance corresponding to many Debye lengths, thereby reaching barometric equilibrium with the local potential. On this same timescale the ions remain stationary. We model this time regime by specifying the “Frozen Ion” analytic space charge formulation (sometimes called “ion matrix”) on the **Space Potentials** tab. (See Section 14.1.) This is based on the assumption that electrons are in barometric equilibrium with the plasma potential but ion density remains uniform at the ambient value.



Charge Density Model

○ Laplace
○ Linear (Debye Shielding)
○ Non-linear
● Frozen ion
○ Barometric
○ Full Trajectory Ions
○ Plume Ion Density
□ Self-Consistent CEX
○ Hybrid PIC
○ Full PIC

□ Geometric Wake Initialization

Species: Oxygen

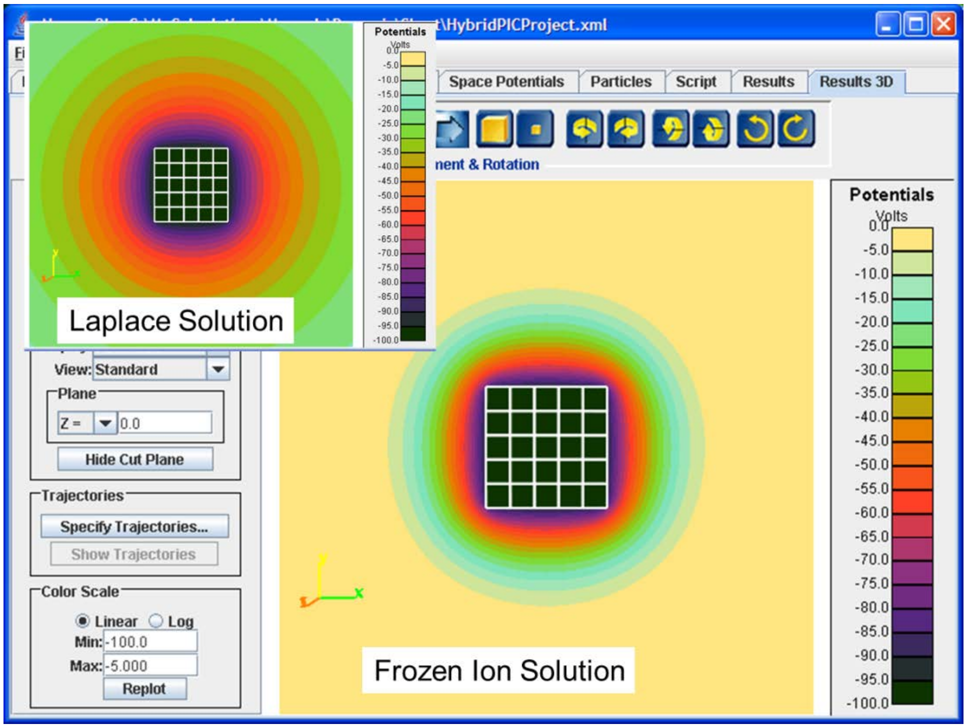
Target Average (RMS) Error (V): 1.000E-4

Minimum Density(m^{-3}): 1.000E9

Number of iterations: 0

Figure 131. Space Potentials Tab for Case 2 of the “Dynamic” Example

The results (after clicking the “Run Script” button) are shown in Figure 132. The potentials extend to much smaller distances from the object because the negative potential is screened by the positive ion space charge. For example, the -5 V contour in the “Frozen Ion” solution is about the same distance from the object as the -45 V contour in the laplace solution, implying that the ion charge within the -5 V contour cancels about 90% of the negative charge on the -100 V cube.



View: Standard

Z = 0.0

● Linear ○ Log

Min: -100.0

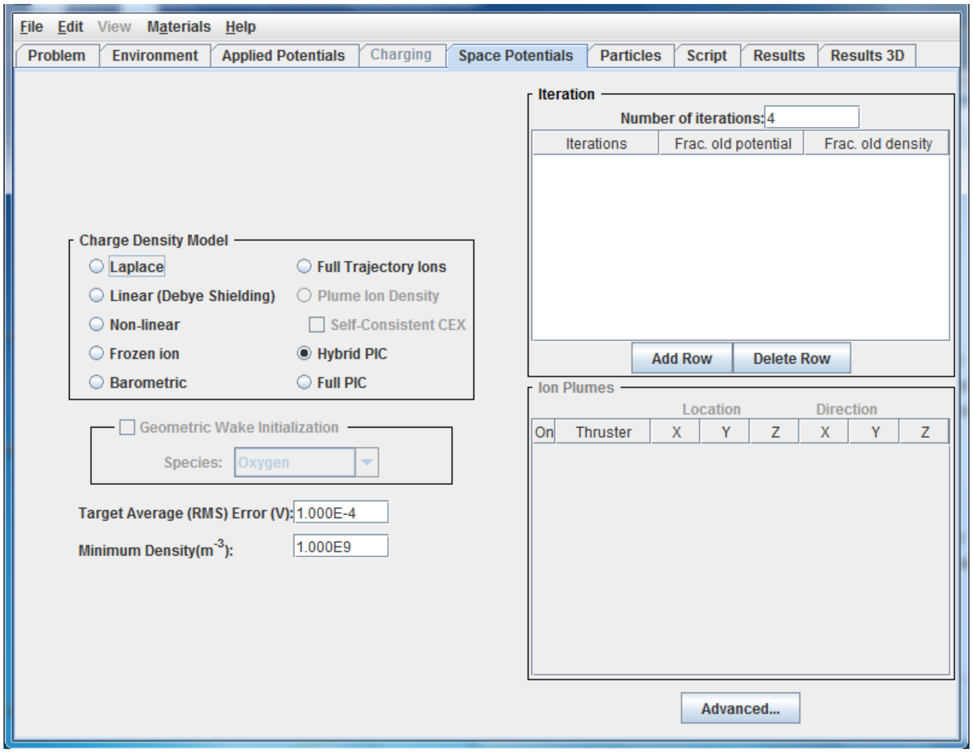
Max: -5.000

Figure 132. Results from Case 2 of the "Dynamic" Example Compared with Laplacian Solution (Upper Left)

21.3.3 Case 3: Time-dependent Ions, Equilibrium (Barometric) Electrons.

After tens to hundreds of microseconds, ions can traverse many Debye lengths as well. We model this time regime using a "Hybrid PIC" formulation for the charge density (Section 14.1) in which the ion density is computed using particle tracking, while electrons are assumed to be in barometric equilibrium.

Figure 124 shows the **Problem** tab for this calculation. Notice that "Time Dependent Plasma" is checked, which in turn enables the "Hybrid PIC" option on the **Space Potentials** tab (Figure 133). We choose four iterations. On the **Time-Dependent Particles** subtab of the **Particles** tab, we choose a uniform initial particle distribution for the first iteration only (Figure 134). We track particles for 1 μs per time step. Figure 135 shows the script for this problem, illustrating the number of iterations to be performed as specified on the user interface. The "0" potential iteration automatically uses "Frozen Ion" analytic space charge instead of "Hybrid PIC."



File Edit View Materials Help

Problem | Environment | Applied Potentials | Charging | Space Potentials | Particles | Script | Results | Results 3D

Charge Density Model

○ Laplace ○ Full Trajectory Ions

○ Linear (Debye Shielding) ○ Plume Ion Density

○ Non-linear □ Self-Consistent CEX

○ Frozen ion ● Hybrid PIC

○ Barometric ○ Full PIC

□ Geometric Wake Initialization

Species: Oxygen

Target Average (RMS) Error (V): 1.000E-4

Minimum Density(m^{-3}): 1.000E9

Iteration

Number of iterations: 4

Iterations	Frac. old potential	Frac. old density

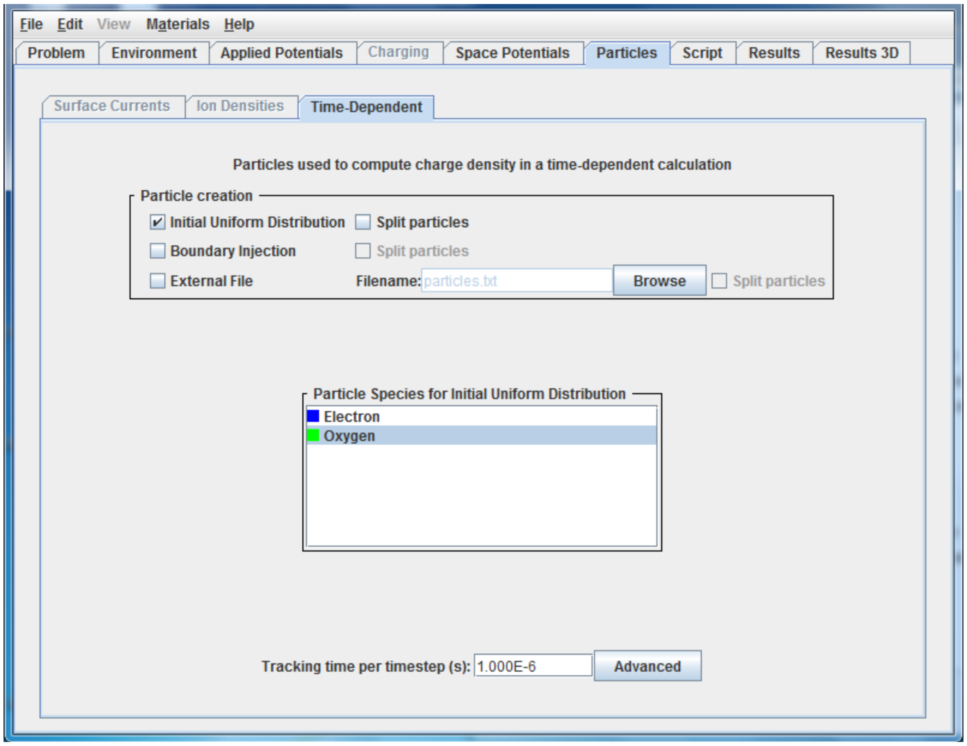
Add Row | Delete Row

Ion Plumes

		Location			Direction		
On	Thruster	X	Y	Z	X	Y	Z

Advanced...

Figure 133. Space Potentials Tab Depicting “Hybrid PIC” Choice for Case 3 of the “Dynamic” Example



File Edit View Materials Help

Problem | Environment | Applied Potentials | Charging | Space Potentials | Particles | Script | Results | Results 3D

Surface Currents | Ion Densities | Time-Dependent

Particles used to compute charge density in a time-dependent calculation

Particle creation

☑ Initial Uniform Distribution □ Split particles

□ Boundary Injection □ Split particles

□ External File Filename: particles.txt Browse □ Split particles

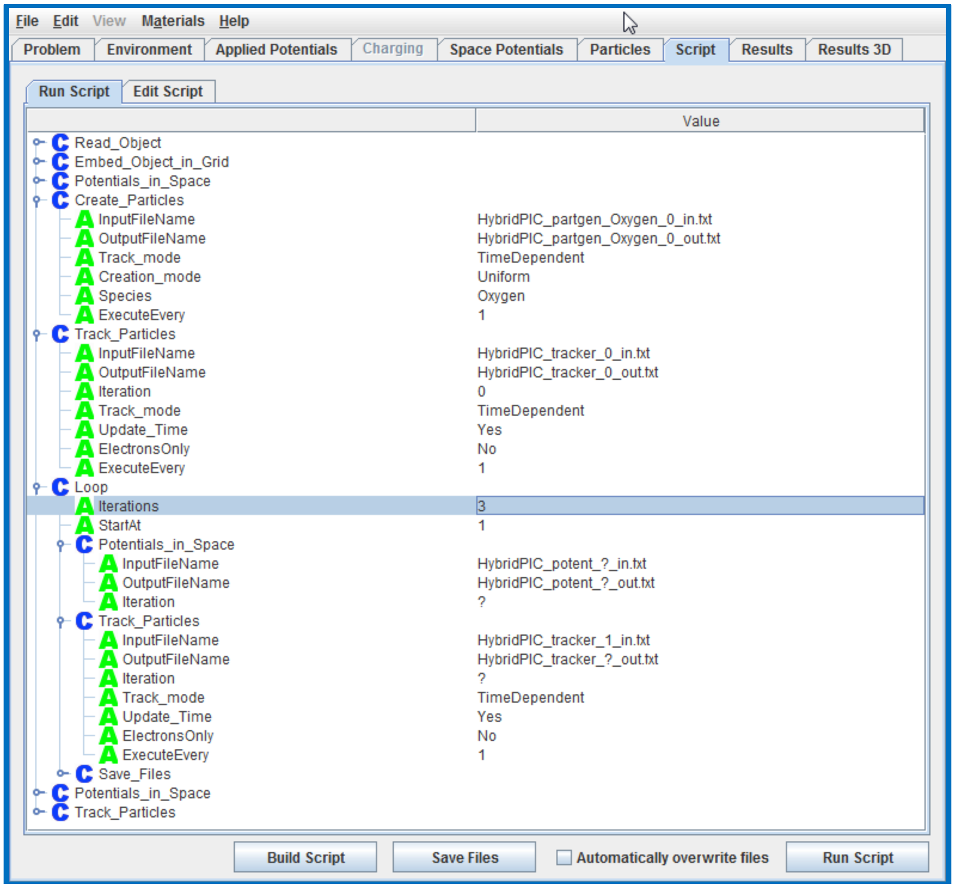
Particle Species for Initial Uniform Distribution

🟦 Electron

🟩 Oxygen

Tracking time per timestep (s): 1.000E-6 Advanced

Figure 134. Time-Dependent Subtab for Case 3 of the “Dynamic” Example



```
                                          Value
C Read_Object
C Embed_Object_in_Grid
C Potentials_in_Space
C Create_Particles
    A InputFileName                       HybridPIC_partgen_Oxygen_0_in.txt
    A OutputFileName                      HybridPIC_partgen_Oxygen_0_out.txt
    A Track_mode                          TimeDependent
    A Creation_mode                       Uniform
    A Species                             Oxygen
    A ExecuteEvery                        1
C Track_Particles
    A InputFileName                       HybridPIC_tracker_0_in.txt
    A OutputFileName                      HybridPIC_tracker_0_out.txt
    A Iteration                           0
    A Track_mode                          TimeDependent
    A Update_Time                         Yes
    A ElectronsOnly                       No
    A ExecuteEvery                        1
C Loop
    A Iterations                          3
    A StartAt                             1
    C Potentials_in_Space
        A InputFileName                   HybridPIC_potent_?_in.txt
        A OutputFileName                  HybridPIC_potent_?_out.txt
        A Iteration                       ?
    C Track_Particles
        A InputFileName                   HybridPIC_tracker_1_in.txt
        A OutputFileName                  HybridPIC_tracker_?_out.txt
        A Iteration                       ?
        A Track_mode                      TimeDependent
        A Update_Time                     Yes
        A ElectronsOnly                   No
        A ExecuteEvery                    1
    C Save_Files
C Potentials_in_Space
C Track_Particles
```

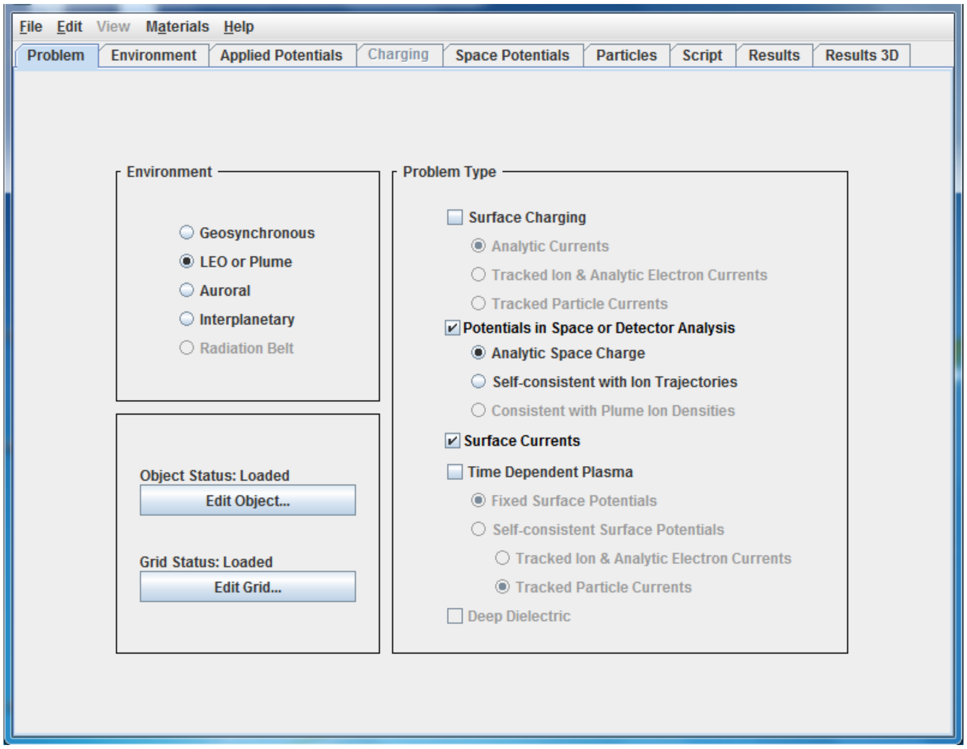
Figure 135. Script for the "Dynamic" Example Showing Four Iterations

Figure 137 shows the **Results 3D** tab depicting oxygen particles on the Z=0 cut plane at the end of the fourth iteration. To plot the particles' locations, choose "Present Particle Positions" in the drop-down list under "Plot" on the **Particle Visualization** dialog box and limit the Z value tracking limits to between 0 and 0.01 m as shown in Figure 138.

Notice that eight particles are created for each (real) grid cube. Also notice the potential profile and the distribution of particles around the object. There is a slight outward extension of the potential by comparison with the "Frozen Ion" solution as ions begin to stream toward the probe, leaving lower densities behind. Current collection also increases over time as ions accelerate towards the negatively biased conductor. From the end of the file **HybridPIC_tracker_4_out.txt**, shown in Figure 139, it can be seen that the current has increased from 46.5 µA at 1 µs to 170 µA at 5 µs.

We can follow the evolution of particles for longer periods of time by restarting the calculation for another, say, six iterations. To avoid redoing the first four iterations again, we simply delete all commands leading up to the **Loop** command (note that this includes **Create Particles** because we have already created them) and then change the **Loop** "Iterations" from "3" to "6" and the **Loop** "StartAt" from "1" to "5." The procedure may be repeated several times but not indefinitely because the solution is at some point in time affected by failure to supply new ion particles at the problem boundaries. Figure 140 shows results after ten iterations. Notice how the potential profile extends farther away from the object as more ions enter the sheath. Figure 141 shows current collected by the cube as a function of time over 20 iterations.

To see how far the solution is from steady state, we can compute the steady-state current value. On the **Problem** tab check the “Potentials in Space or Detector Analysis” checkbox and select the Analytic Space Charge option, and check the “Surface Currents” checkbox (Figure 136). The “Non-Linear” Charge Density Model is chosen on the **Space Potentials** tab. In the **Surface Currents** subtab of the **Particles** tab, “Oxygen” should be selected as the “Particle Species” and the “Initial Particle Distribution” should be “Sheath.” Figure 142 shows the steady-state potential profile. The collected current is 25 µA for a sheath potential of 0.138 V. These values can be found in the tracker output and potent output files, respectively.



Environment

○ Geosynchronous
● LEO or Plume
○ Auroral
○ Interplanetary
○ Radiation Belt

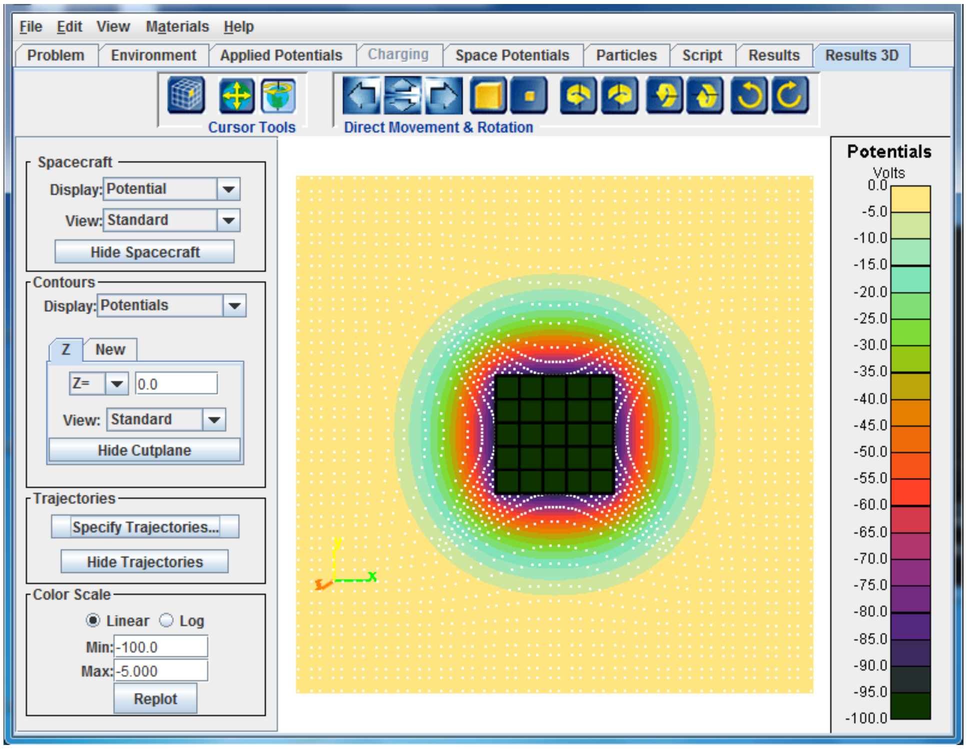
Object Status: Loaded

Grid Status: Loaded

Problem Type

□ Surface Charging
● Analytic Currents
○ Tracked Ion & Analytic Electron Currents
○ Tracked Particle Currents
☑ Potentials in Space or Detector Analysis
● Analytic Space Charge
○ Self-consistent with Ion Trajectories
○ Consistent with Plume Ion Densities
☑ Surface Currents
□ Time Dependent Plasma
● Fixed Surface Potentials
○ Self-consistent Surface Potentials
○ Tracked Ion & Analytic Electron Currents
● Tracked Particle Currents
□ Deep Dielectric

Figure 136. Problem Tab for Case 3 of the “Dynamic” Example



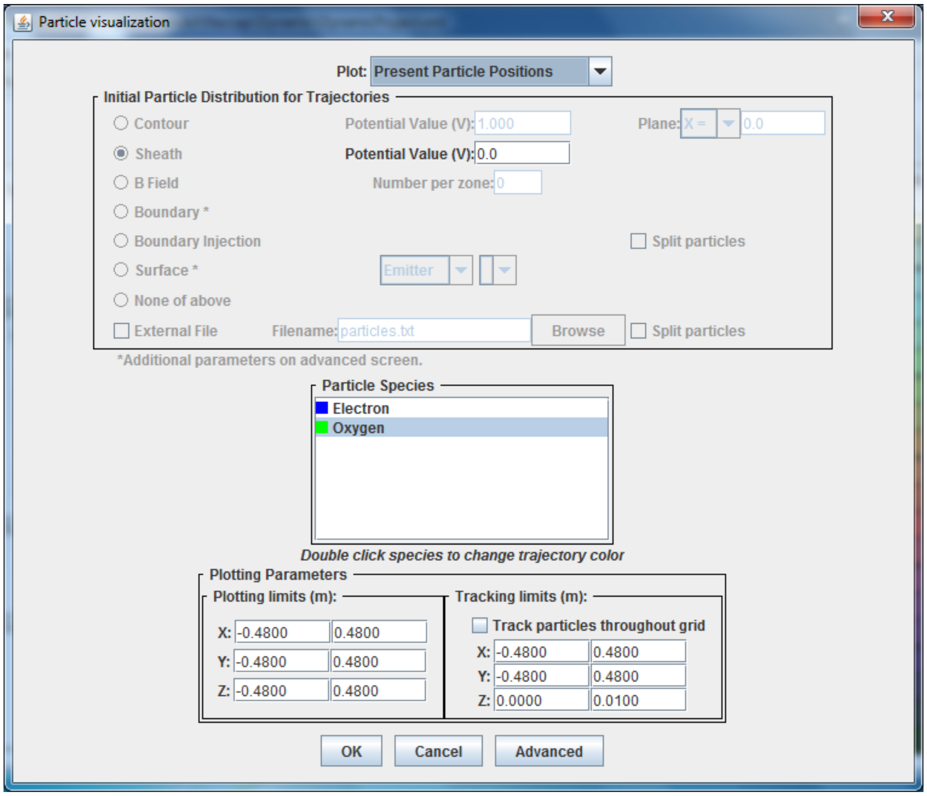
Spacecraft
Display: Potential
View: Standard

Contours
Display: Potentials
Z New
Z= 0.0
View: Standard

Trajectories

Color Scale
● Linear ○ Log
Min: -100.0
Max: -5.000

Figure 137. Particle Distribution for Case 3 of the "Dynamic" Example at t=4 μs



Plot: Present Particle Positions

Initial Particle Distribution for Trajectories
○ Contour Potential Value (V): 1.000 Plane: X = 0.0
● Sheath Potential Value (V): 0.0
○ B Field Number per zone: 0
○ Boundary *
○ Boundary Injection □ Split particles
○ Surface * Emitter
○ None of above
□ External File Filename: particles.txt □ Split particles

*Additional parameters on advanced screen.

Particle Species
🟦 Electron
🟩 Oxygen

Double click species to change trajectory color

Plotting Parameters

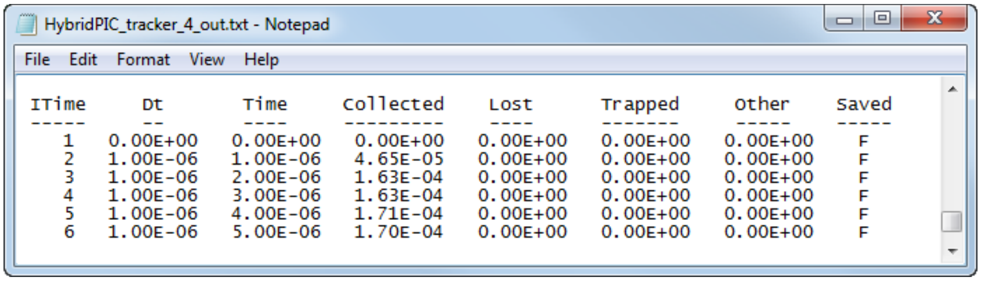
Plotting limits (m):

X:	-0.4800	0.4800
Y:	-0.4800	0.4800
Z:	-0.4800	0.4800

Tracking limits (m):
□ Track particles throughout grid

X:	-0.4800	0.4800
Y:	-0.4800	0.4800
Z:	0.0000	0.0100

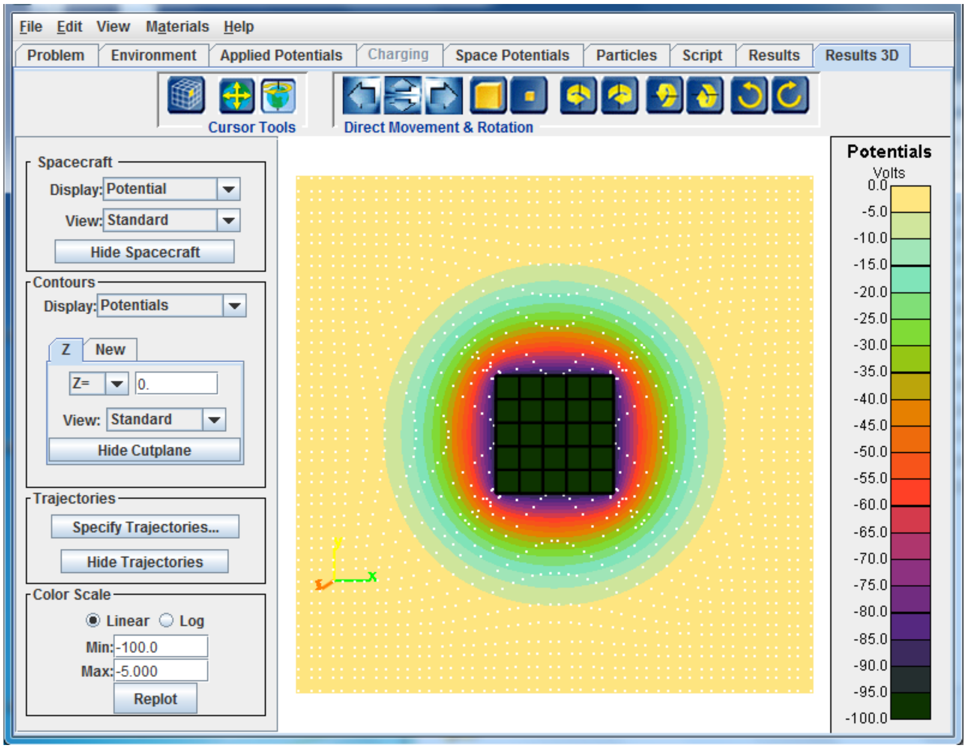
Figure 138. Particle Visualization Dialog Box Selections to Display Particle Locations



HybridPIC_tracker_4_out.txt - Notepad
File Edit Format View Help

```
ITime      Dt          Time        Collected    Lost         Trapped      Other        Saved
-----      --          ----        ---------    ----         -------      -----        -----
   1    0.00E+00    0.00E+00    0.00E+00    0.00E+00    0.00E+00    0.00E+00      F
   2    1.00E-06    1.00E-06    4.65E-05    0.00E+00    0.00E+00    0.00E+00      F
   3    1.00E-06    2.00E-06    1.63E-04    0.00E+00    0.00E+00    0.00E+00      F
   4    1.00E-06    3.00E-06    1.63E-04    0.00E+00    0.00E+00    0.00E+00      F
   5    1.00E-06    4.00E-06    1.71E-04    0.00E+00    0.00E+00    0.00E+00      F
   6    1.00E-06    5.00E-06    1.70E-04    0.00E+00    0.00E+00    0.00E+00      F
```

Figure 139. Partial contents of the HybridPIC_tracker_4_out.txt file showing total current collected for first five timesteps



Display: Potential
View: Standard

Display: Potentials
Z= 0.
View: Standard

● Linear ○ Log
Min: -100.0
Max: -5.000

Figure 140. Particle Distribution for Case 3 of the "Dynamic" Example at t=10 μs

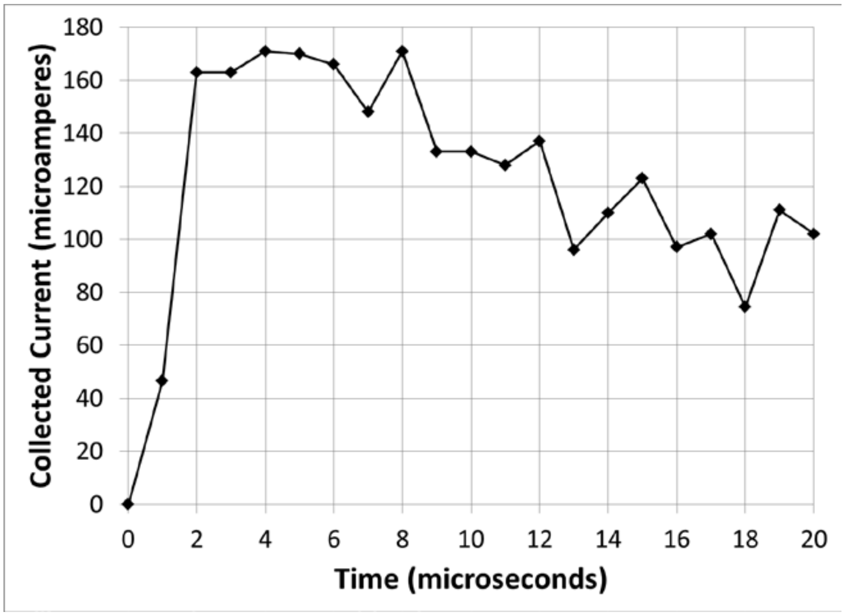
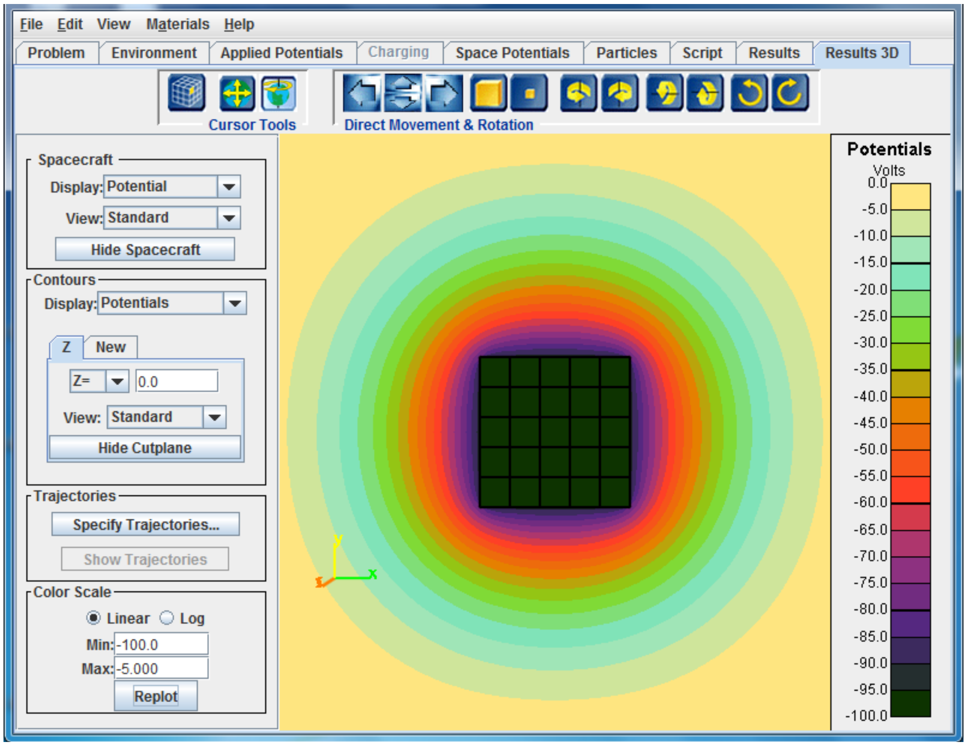


Figure 141. Ion Collection (Current) by Gold-plated Cube as a Function of Time for Case 3 of the "Dynamic" Example



Display: Potential

View: Standard

Display: Potentials

Z= 0.0

View: Standard

● Linear ○ Log

Min: -100.0

Max: -5.000

Figure 142. Steady-state Potential Profile for Comparison with Transient Results for the "Dynamic" Example

22 Additional Examples

The following are examples of some specialized capabilities.

22.1 Detector

This example illustrates how to use the detector capability by computing the current to a detector with a guard ring.

22.1.1 Object and Grid

The object and grid are found in the **Example Problems/Detector** folder. The object, which represents a detector with a rudimentary collimator, is shown in Figure 143. The object consists of a box (green surface elements) with the element in the center of the top defined as the detector (cyan surface element) and a hollowed out cone (yellow surface elements) representing the collimator. The detector and eight surrounding elements forming the guard ring (green surface elements) are defined as conductor 3, so that they can be biased +5 V relative to the plate (remaining green surface elements) and collimator.

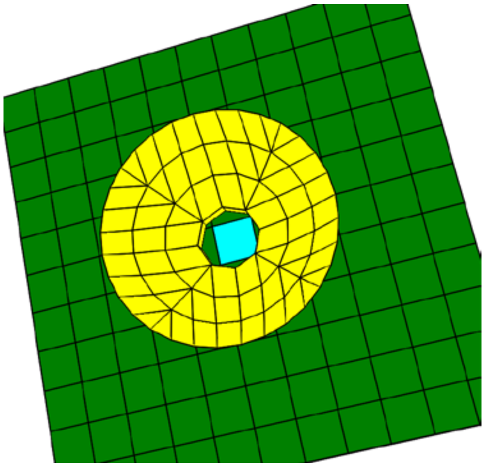
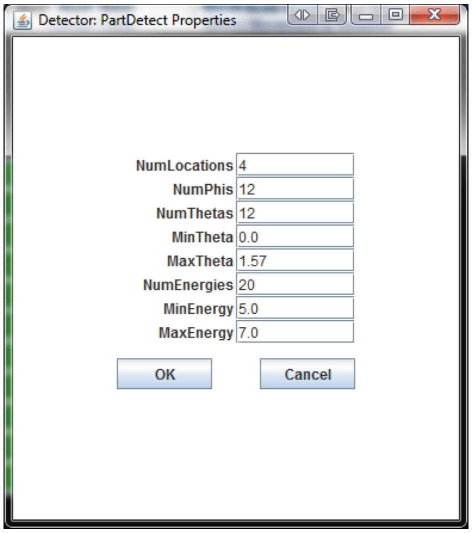


Figure 143. Object for "Detector" Example

The detector was defined in *Object Toolkit* to have the properties shown in Figure 144. It specifies the emission of test particles from four locations on the detector in 144 directions and with 20 energies ranging from 5 eV (0 eV of total energy) to 7 eV (2 eV of total energy).



NumLocations 4
NumPhis 12
NumThetas 12
MinTheta 0.0
MaxTheta 1.57
NumEnergies 20
MinEnergy 5.0
MaxEnergy 7.0

Figure 144. Definition of the Detector "PartDetect" of the "Detector" Example

The outer grid is 56 × 56 × 56 elements with size 0.0167 m. One inner grid encompassing the region about the collimator is defined. It extends from 22 to 36 in the x and y directions and from 16 to 30 in the z direction.

22.1.2 Problem Specification

On the **Problem** tab, specify the environment as "LEO or Plume" and the problem type as "Potentials in Space or Detector Analysis" with "Analytic Space Charge" and "Surface Currents".

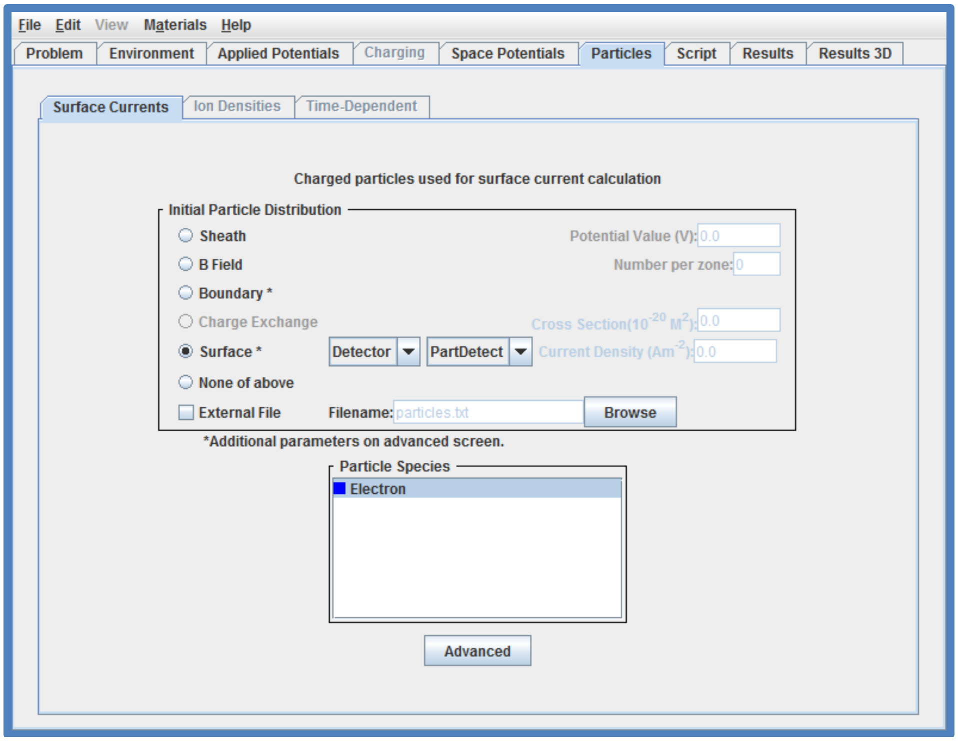
On the **Environment** tab specify a plasma with density 10^{11} m^{-3}, temperature 0.3 eV, and no motion or magnetic field.

On the **Applied Potentials** tab, set conductor 1 as fixed at 0 V (ground), conductor 2 (collimator) biased to 0 V (grounded), and conductor 3 (detector and guard ring) biased to +5 V.

On the **Space Potentials** tab, set the charge density formulation to be "Non-linear".

On the **Particles** tab (Figure 145), specify "Electron" emission from a "Surface" using the "Detector" treatment. The specifications for the "PartDetect" detector were defined during object definition using *Object Toolkit* and can be modified on the **Advanced Particles Parameters** dialog box shown in Figure 146.

Once the above settings have been specified, the script can be created and executed. To build the script click "Build Script" on the **Script** tab. The script is the same as for the other current collection calculation examples with an analytic representation of the plasma environment ("Bipolar" Cases 1 and 2, "CHAWS" Cases 1 and 2, and "Dynamic" Cases 1 and 2). However, the input file for the **Create Particles** command specifies that the reverse trajectory technique is to be used to compute currents for the particles created. Then, run the script to obtain the results discussed in the following section.


File Edit View Materials Help
Problem | Environment | Applied Potentials | Charging | Space Potentials | Particles | Script | Results | Results 3D
Surface Currents | Ion Densities | Time-Dependent
Browse
Advanced

Charged particles used for surface current calculation

Initial Particle Distribution

○ Sheath — Potential Value (V): 0.0

○ B Field — Number per zone: 0

○ Boundary *

○ Charge Exchange — Cross Section(10^{-20} M^2): 0.0

● Surface * — Detector ▾ — PartDetect ▾ — Current Density (Am^{-2}): 0.0

○ None of above

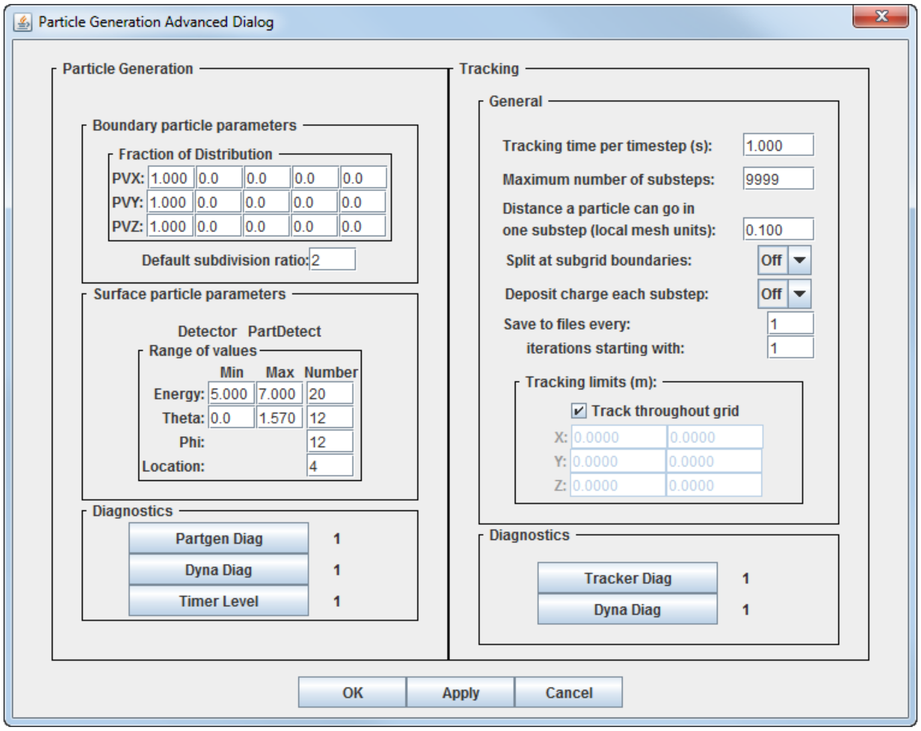
□ External File — Filename: particles.txt

*Additional parameters on advanced screen.

Particle Species

- ■ Electron

Figure 145. Particles Tab for the "Detector" Example



Particle Generation

Boundary particle parameters

Fraction of Distribution

PVX:	1.000	0.0	0.0	0.0	0.0
PVY:	1.000	0.0	0.0	0.0	0.0
PVZ:	1.000	0.0	0.0	0.0	0.0

Default subdivision ratio: 2

Surface particle parameters

Detector PartDetect

Range of values

	Min	Max	Number
Energy:	5.000	7.000	20
Theta:	0.0	1.570	12
Phi:			12
Location:			4

Diagnostics

Partgen Diag 1

Dyna Diag 1

Timer Level 1

Tracking

General

Tracking time per timestep (s): 1.000

Maximum number of substeps: 9999

Distance a particle can go in one substep (local mesh units): 0.100

Split at subgrid boundaries: Off ▾

Deposit charge each substep: Off ▾

Save to files every: 1

iterations starting with: 1

Tracking limits (m):

☑ Track throughout grid

X:	0.0000	0.0000
Y:	0.0000	0.0000
Z:	0.0000	0.0000

Diagnostics

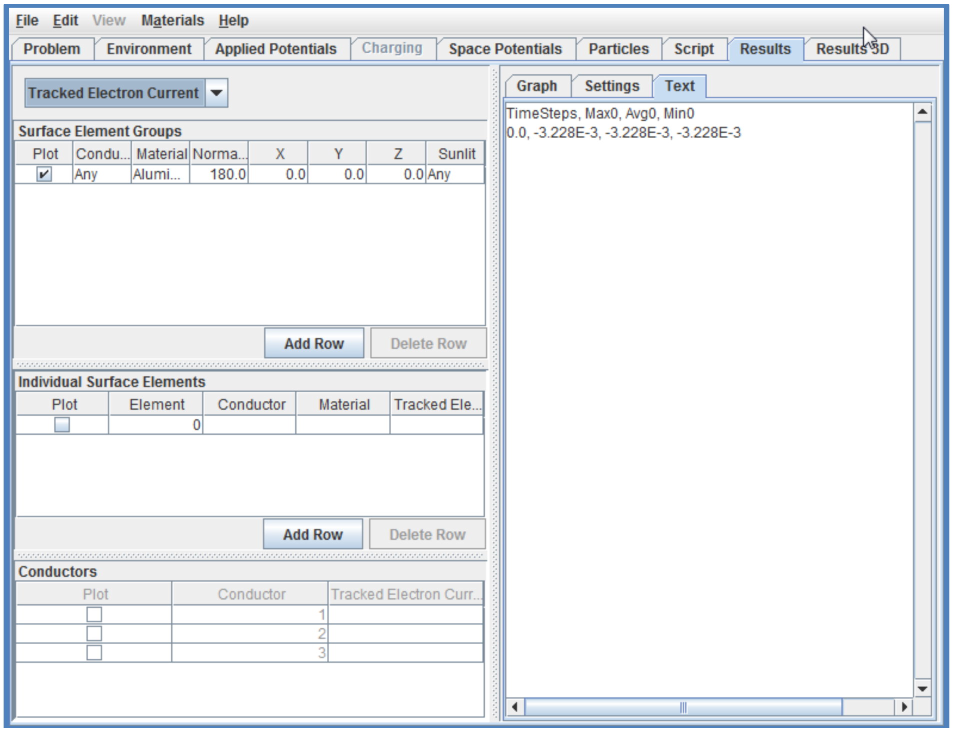
Tracker Diag 1

Dyna Diag 1

Figure 146. Advanced Particle Parameters Dialog Box for "Detector" Example

22.1.3 Results

The current density to the detector can be obtained from the **Results** tab by displaying the "Tracked Electron Current" to all the surfaces of "Material" Aluminum (i.e., to the element corresponding to the detector) as shown in Figure 147. The current density is -3.228 mA m^{-2}, which for an area of 0.00132 m^2 gives a total current of 4.26 µA. The Surface Element Information Tool (see Section 17.2) can be used to obtain the surface area of the detector element.



Surface Element Groups

Plot	Condu...	Material	Norma...	X	Y	Z	Sunlit
☑	Any	Alumi...	180.0	0.0	0.0	0.0	Any

Individual Surface Elements

Plot	Element	Conductor	Material	Tracked Ele...
□	0			

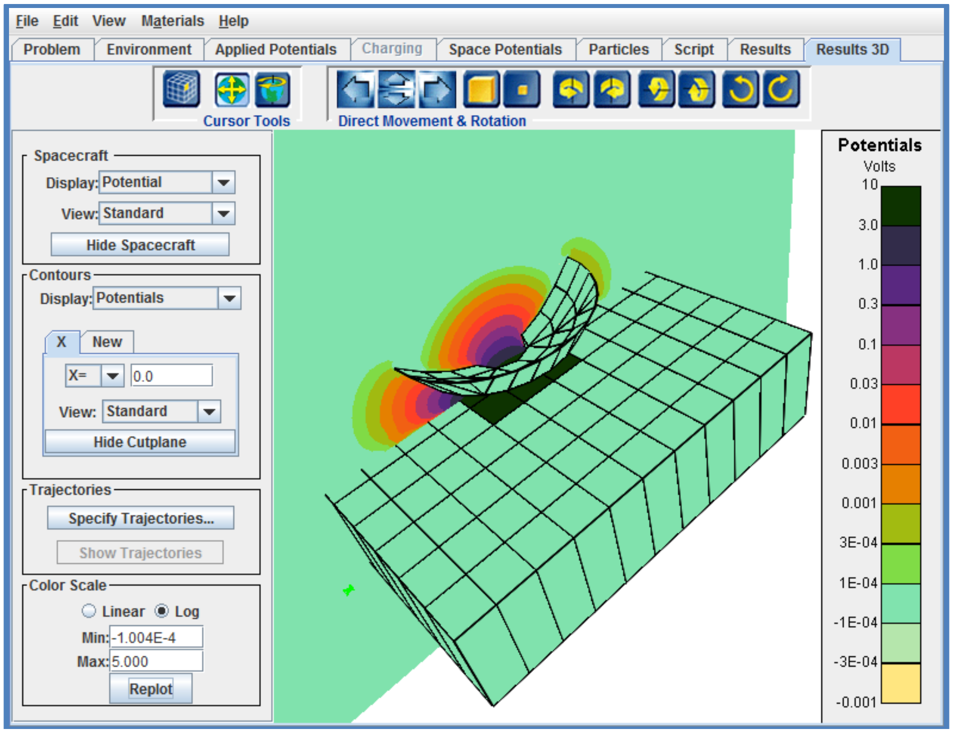
Conductors

Plot	Conductor	Tracked Electron Curr...
□	1	
□	2	
□	3	

```
TimeSteps, Max0, Avg0, Min0
0.0, -3.228E-3, -3.228E-3, -3.228E-3
```

Figure 147. Results Tab for "Detector" Example Following Execution

The potentials can be seen on the **Results3D** tab, shown in Figure 148. The color scale is reversed from the default using the "Color Scale Direction" option on the **View** menu. The potential bows out significantly from the collimator aperture, suggesting that the current is somewhat greater than the aperture area times the electron thermal current. Since the aperture approximates a circle of 2.5 cm radius and the electron thermal current is 1.468 mA m^{-2} (shown on the **Environment** tab), the planar current through the aperture would be only 2.9 µA. (By comparison, a sheath calculation with the sheath potential set to 0.2 V gives 3.4 µA to the detector surface element.)



Display: Potential

View: Standard

Display: Potentials

X= 0.0

View: Standard

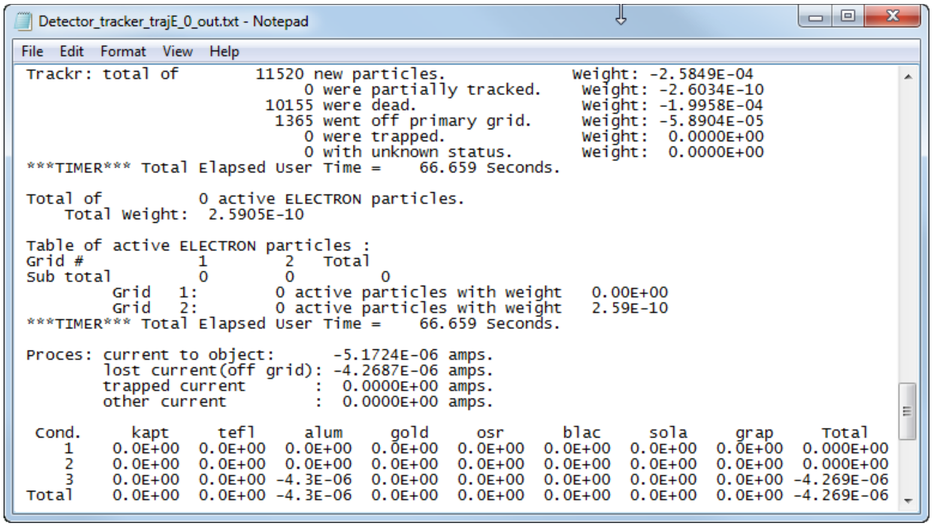
○ Linear ● Log

Min: -1.004E-4

Max: 5.000

Figure 148. Results3D tab Showing Bowing Out of Potentials Through the Collimator

Additional information can be found in the **Track Particles** output file, **Detector_tracker_trajE_0_out.txt**, the relevant excerpt of which is shown in Figure 149. Of 11520 test particles launched from the detector surface element, 1365 left the primary grid (meaning that they represent electrons from the environment), while 10155 struck object surfaces (meaning they represent phase space that does not connect to the environment). The code applies environmental factors to the “lost” current particle weights to yield the 4.3 µA noted above. This current is assigned to conductor 3 “Alum” surface elements (representing the detector). Applying environmental factors to the 10155 test particles that struck the object yields 5.14 µA; this is not necessarily a meaningful number as these particles do not represent electrons from the environment, but gives a better estimate than the raw particle numbers or weights of how much of the detector’s phase space is blocked. The question of which surfaces block which portion of phase space can be explored by defining the detector as an emitter and using the same particle definitions. As the particles are distributed evenly in the cosine of the polar angle, the test particles at near normal angles represent a larger fraction of phase space than those at glancing incidence.



```
Trackr: total of        11520 new particles.             Weight: -2.5849E-04
                             0 were partially tracked.    Weight: -2.6034E-10
                         10155 were dead.                 Weight: -1.9958E-04
                          1365 went off primary grid.     Weight: -5.8904E-05
                             0 were trapped.              Weight:  0.0000E+00
                             0 with unknown status.       Weight:  0.0000E+00
***TIMER*** Total Elapsed User Time =    66.659 Seconds.

Total of          0 active ELECTRON particles.
    Total Weight:  2.5905E-10

Table of active ELECTRON particles :
Grid #            1        2   Total
Sub total         0        0         0
         Grid   1:        0 active particles with weight   0.00E+00
         Grid   2:        0 active particles with weight   2.59E-10
***TIMER*** Total Elapsed User Time =    66.659 Seconds.

Proces: current to object:      -5.1724E-06 amps.
        lost current(off grid): -4.2687E-06 amps.
        trapped current       :  0.0000E+00 amps.
        other current         :  0.0000E+00 amps.

 Cond.     kapt     tefl     alum     gold     osr      blac     sola     grap      Total
    1    0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00   0.000E+00
    2    0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00   0.000E+00
    3    0.0E+00  0.0E+00 -4.3E-06  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  -4.269E-06
Total    0.0E+00  0.0E+00 -4.3E-06  0.0E+00  0.0E+00  0.0E+00  0.0E+00  0.0E+00  -4.269E-06
```

Figure 149. Tracker Output from Detector Run.

22.2 Current Balance in a System with an Electron Gun (Emitter)

In this example, the floating potential of an object on which an electron gun is mounted is computed. The current balance is between the electron current from the electron gun and sheath electrons collected from a LEO plasma, including limiting by a magnetic field. This calculation illustrates how to specify a current balance simulation in which the sources of current are determined differently. It also illustrates how *Nascap-2k*'s algorithms interact with user choices to determine the rate of charging.

22.2.1 Object and Grid

The object and grid are found in the **Example Problems/Emitter** folder. The object is a 1 m long, 0.4 m diameter, aluminum cylinder with the long axis along z, as shown in Figure 150. One side surface is the emitter “EGun.” The properties of “EGun” were defined in *Object Toolkit* to be as shown in Figure 151. The electron gun emits 0.3 Am^{-2} of 3 keV electrons from a surface of area of 0.03451 m^{-2}, for a total current of 10.35 mA. The current is represented by a single macroparticle.

The computational space is three nested grids with a 20 cm resolution outer grid and a 5 cm resolution inner grid.

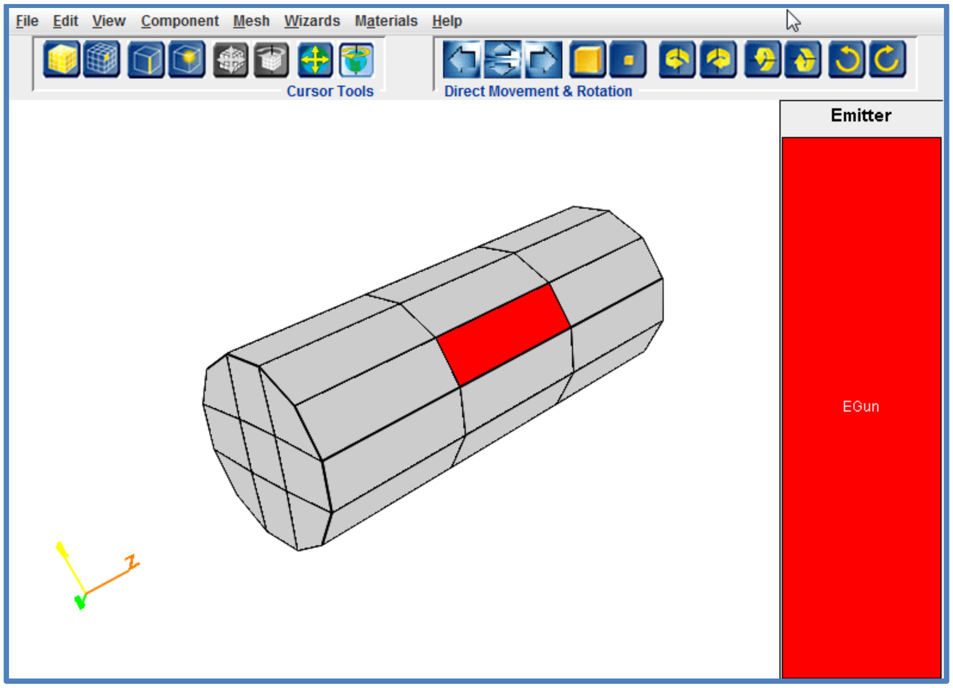
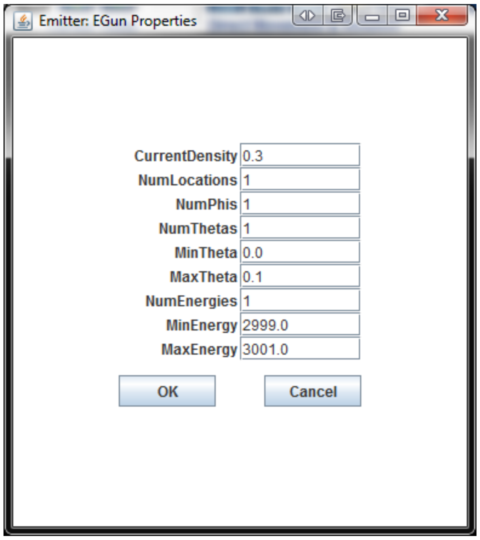

File Edit View Component Mesh Wizards Materials Help
Cursor Tools
Direct Movement & Rotation
Emitter
EGun
z

Figure 150. Aluminum Cylinder Showing Emitter Surface Element



Emitter: EGun Properties

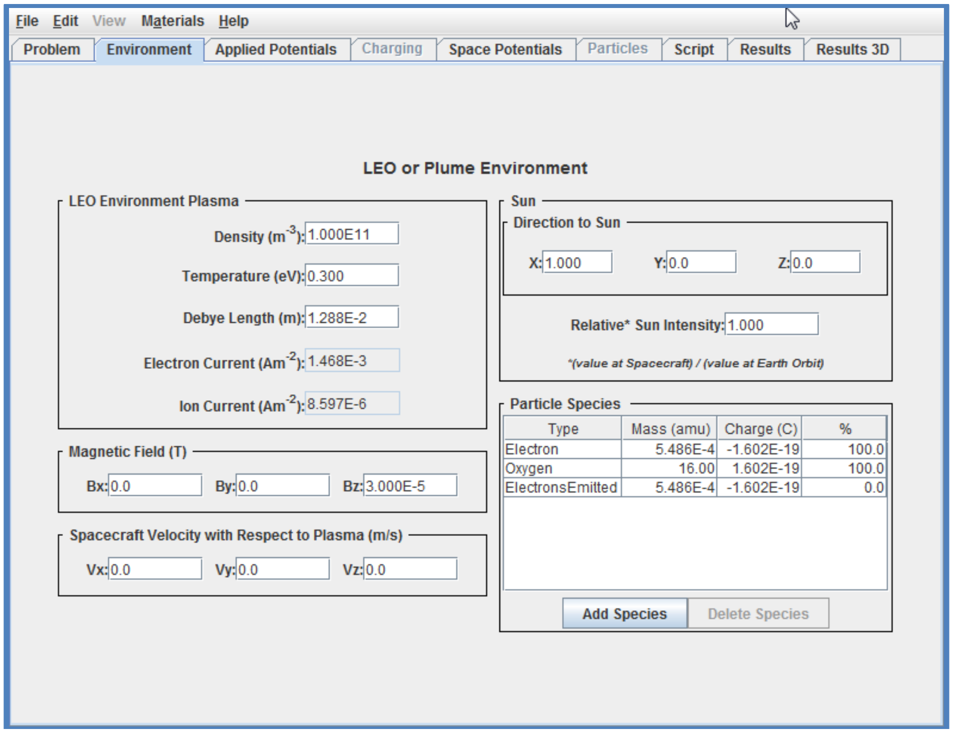
CurrentDensity	0.3
NumLocations	1
NumPhis	1
NumThetas	1
MinTheta	0.0
MaxTheta	0.1
NumEnergies	1
MinEnergy	2999.0
MaxEnergy	3001.0

Figure 151. Definition of the Emiter “EGun” of the “Emitter” Example

22.2.2 Problem Specification

On the **Problem** tab, specify the environment as “LEO or Plume” and the problem type as “Charging” with “Tracked Particle Currents”.

On the **Environment tab** specify a plasma with density 10^{11} m^{-3}, temperature 0.3 eV, and a magnetic field of 3 × 10^{-5} tesla along z (parallel to the cylinder axis). Also, define an extra species to represent the emitted electrons. These settings are shown in Figure 152.



LEO or Plume Environment

LEO Environment Plasma

Density (m^{-3}): 1.000E11

Temperature (eV): 0.300

Debye Length (m): 1.288E-2

Electron Current (Am^{-2}): 1.468E-3

Ion Current (Am^{-2}): 8.597E-6

Magnetic Field (T)

Bx: 0.0 By: 0.0 Bz: 3.000E-5

Spacecraft Velocity with Respect to Plasma (m/s)

Vx: 0.0 Vy: 0.0 Vz: 0.0

Sun

Direction to Sun

X: 1.000 Y: 0.0 Z: 0.0

Relative* Sun Intensity: 1.000

*(value at Spacecraft) / (value at Earth Orbit)

Particle Species

Type	Mass (amu)	Charge (C)	%
Electron	5.486E-4	-1.602E-19	100.0
Oxygen	16.00	1.602E-19	100.0
ElectronsEmitted	5.486E-4	-1.602E-19	0.0

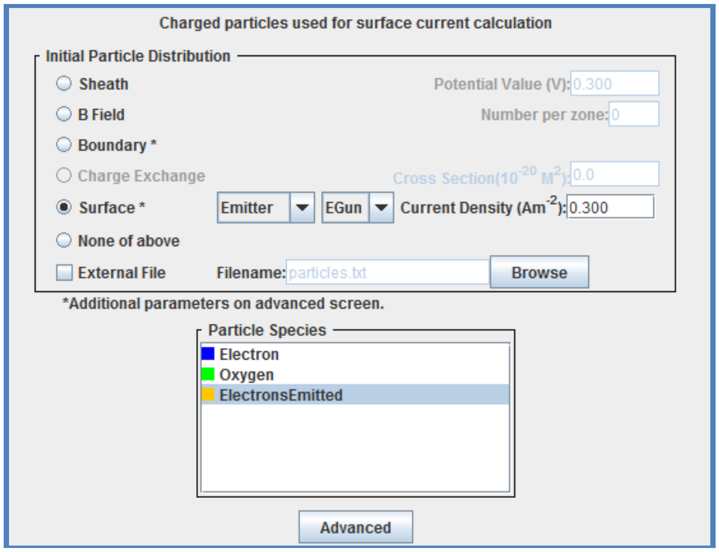
Figure 152. Environment Tab for "Emitter" Example.

On the **Applied Potentials** tab, set the conductor to be floating with an initial potential of +5 V.

On the **Charging** tab, set the calculation to proceed with 20 0.1 ms timesteps for a total of 2 ms charging time.

On the **Space Potentials** tab, specify that the "Non-linear" charge density model is to be used. Note that the 20 iterations also appears on this tab.

On the **Particles** tab (Figure 153), specify that particles of type "ElectronsEmitted" are to be emitted from a "Surface" representing an "Emitter". The properties of the "Emitter" "EGun" were specified during object definition and can be modified on the **Advanced Particles Parameters** dialog.



Charged particles used for surface current calculation

Initial Particle Distribution

○ Sheath Potential Value (V): 0.300

○ B Field Number per zone: 0

○ Boundary *

○ Charge Exchange Cross Section(10^{-20} M^2): 0.0

● Surface * Emitter ▾ EGun ▾ Current Density (Am^{-2}): 0.300

○ None of above

□ External File Filename: particles.txt

*Additional parameters on advanced screen.

Particle Species

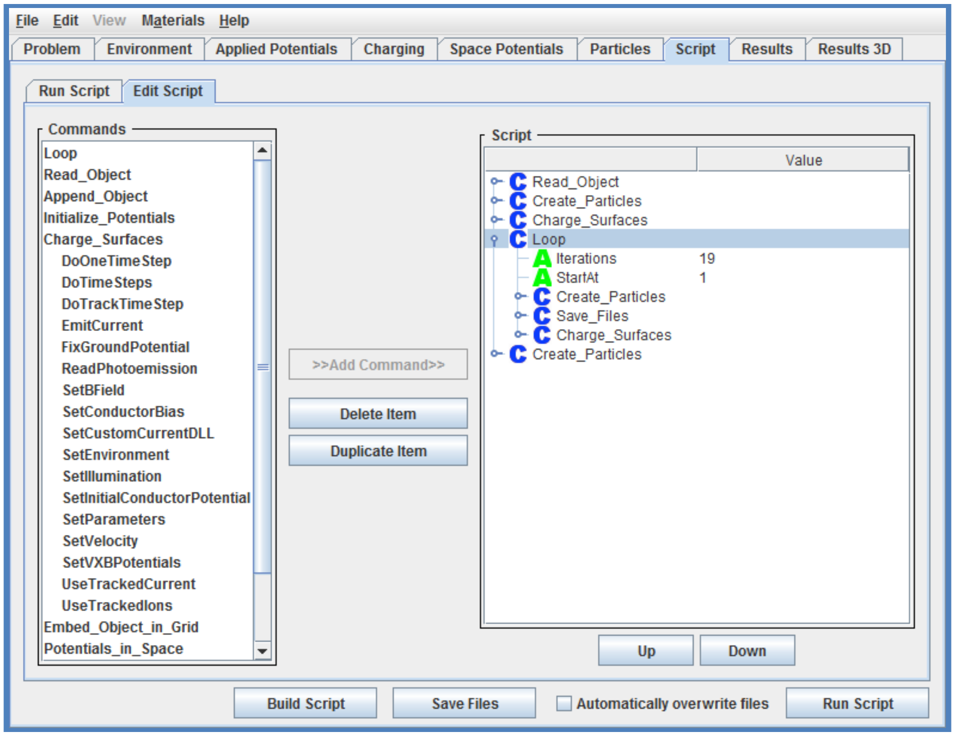
🟦 Electron
🟩 Oxygen
🟨 ElectronsEmitted

Figure 153. Particles Tab Specification for Emitter Electrons.

22.2.3 Building and Modifying the Script

The problem as specified so far only includes the emitter current, so the cylinder would continue to charge to the energy of the emitted electrons. In order to also include the collection of electrons from the sheath, separate input files for the two sources of electrons are needed. The approach we'll use is to first create the input files to specify the creation of the macroparticles representing the emitter electrons and then specify a current balance problem between two tracked current sources. The calculation will then be performed using the previously written input file for the electrons from the emitter.

Start on the **Script** tab by clicking the "Build Script" button to create the default script. Then delete all of the **Embed Object in Grid**, **Potentials in Space**, and **Track Particles** commands. To delete a command, highlight the command and then click the "Delete Item" button. The resulting script looks as shown in Figure 154. In the resulting script, the only commands left that take an input file are the **CreateParticles** commands. Click the "Save Files" button to save the input files.

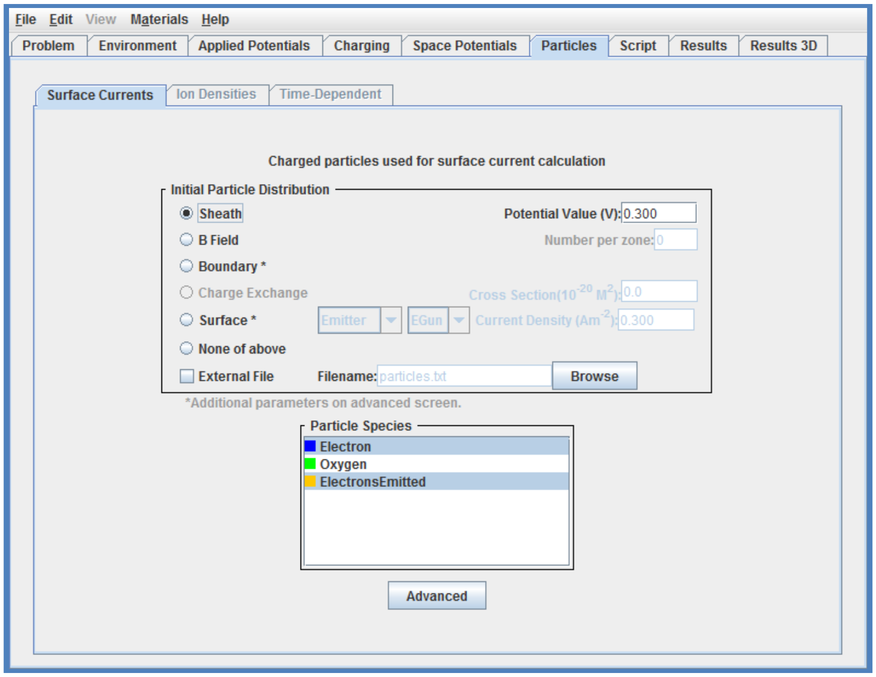


```
C Read_Object
C Create_Particles
C Charge_Surfaces
C Loop
    A Iterations        19
    A StartAt           1
    C Create_Particles
    C Save_Files
    C Charge_Surfaces
C Create_Particles
```

□ Automatically overwrite files

Figure 154. Edited Script Used to Write Input Files for Creating Macroparticles to Represent those Originating at the Emitter

Now that we have the input files for the particles emitted by the emitter, return to the **Particles** tab and specify parameters for tracking particles from a sheath, as shown in Figure 155. As we want to generate a script and “Track Particles” input files for both species, select both “Electrons” and “ElectronsEmitted” here. While these settings alone would specify tracking both species from a sheath, the input files to create particles on the surface of an emitter of species “ElectronsEmitted” that have already been created will be used.



Charged particles used for surface current calculation

Initial Particle Distribution

● Sheath Potential Value (V): 0.300
○ B Field Number per zone: 0
○ Boundary *
○ Charge Exchange Cross Section(10^{-20} M^2): 0.0
○ Surface * Emitter EGun Current Density (Am^{-2}): 0.300
○ None of above
□ External File Filename: particles.txt

*Additional parameters on advanced screen.

Particle Species

🟦 Electron
🟩 Oxygen
🟨 ElectronsEmitted

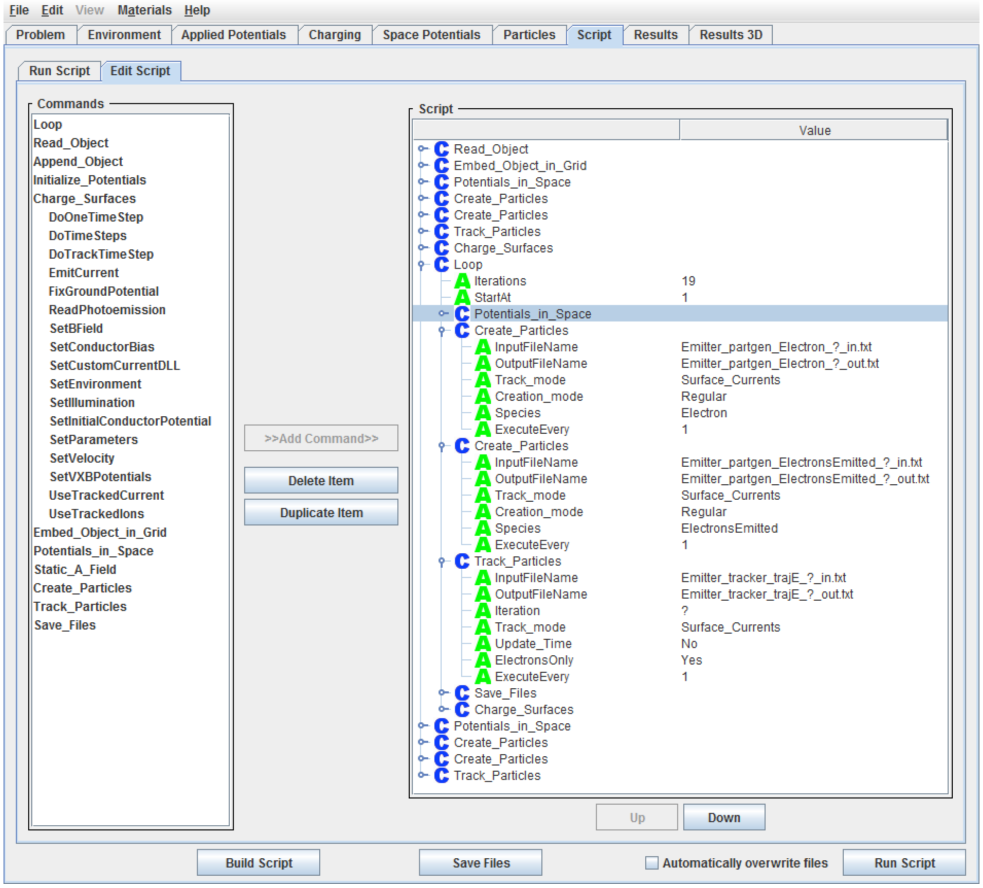
Figure 155. Particles Tab Specification for Sheath Electrons

Return to the **Script** tab and click the "Build Script" button to build the default script shown in Figure 156. This script iteratively performs the following computation:

- Compute potentials throughout the computational space.
- Create macroparticles with properties specified in the previously generated input files **Emitter_partgen_ElectronsEmitted_?_in.txt** . When performing the calculation, it is important to make sure that the previously computed input files are used.
- Create macroparticles with properties specified in newly generated input files **Emitter_partgen_Electron_?_in.txt**. These files will be constructed based on the selections on the **Particles** tab when the "Run Script" button is clicked.
- Track the species selected on the **Particles** tab, that is "ElectronsEmitted" from the emitter and "Electrons" from the sheath of the positive spacecraft. (The option "Yes" for the "ElectronsOnly" keyword in the script specifies that the tracked charge is to be stored in electron specific arrays. This distinction is needed for some calculations using the "Full PIC" charge density model.)
- Compute new surface potentials using the surface currents just computed.

In order to use the input files already created, make sure that the *"Automatically overwrite files" box is unchecked*.

Finally, click the "Run Script" button and click "No to All" in response to the "Do you want to overwrite the existing file?" question.



```
Read_Object
Embed_Object_in_Grid
Potentials_in_Space
Create_Particles
Create_Particles
Track_Particles
Charge_Surfaces
Loop
    Iterations                 19
    StartAt                    1
    Potentials_in_Space
    Create_Particles
        InputFileName          Emitter_partgen_Electron_?_in.txt
        OutputFileName         Emitter_partgen_Electron_?_out.txt
        Track_mode             Surface_Currents
        Creation_mode          Regular
        Species                Electron
        ExecuteEvery           1
    Create_Particles
        InputFileName          Emitter_partgen_ElectronsEmitted_?_in.txt
        OutputFileName         Emitter_partgen_ElectronsEmitted_?_out.txt
        Track_mode             Surface_Currents
        Creation_mode          Regular
        Species                ElectronsEmitted
        ExecuteEvery           1
    Track_Particles
        InputFileName          Emitter_tracker_trajE_?_in.txt
        OutputFileName         Emitter_tracker_trajE_?_out.txt
        Iteration              ?
        Track_mode             Surface_Currents
        Update_Time            No
        ElectronsOnly          Yes
        ExecuteEvery           1
    Save_Files
    Charge_Surfaces
Potentials_in_Space
Create_Particles
Create_Particles
Track_Particles
```

Figure 156. Final Script for Current Balance Calculation

22.2.4 Results

The final potential shown on the **Results** tab is 840 V. The potential versus time is shown in Figure 157. Using the vacuum capacitance, one would expect the cylinder to charge at a rate on the order of 100s of volts per microsecond. For stability, *Nascap-2k* limits the change in potential in a single timestep by adding a dJ/dV term to the charging equation. For this calculation, early on, the charging rate is limited by the dJ/dV, which, for calculations with only tracked currents, is set to 0.75J/V. The potential increases until the sheath current balances the emitter current at about 840 V. The charging rate continues to be limited because the code sets

$$\frac{dI}{dV}=\sum_{elem}\frac{dJ}{dV}=-0.75\sum_{elem}\left|\frac{J}{V}\right|<<-0.75\left|\frac{I}{V}\right|$$

. i.e, dI/dV is large and negative even though I is near zero due to cancellation of the emitted and sheath electrons.

The net current versus potential is shown in Figure 158. At about 840 V the sheath electron current cancels the emitter current. The net current is obtained by taking the average “Tracked Electron Current” to all surface elements and multiplying by the total area of 1.4823 m^2.

If the option is used to set the stabilizing current derivatives to zero, then the correct (using the vacuum capacitance) charging timescale (microseconds) is achieved, as shown in Figure 159.

Note that the floating potential depends on the electron plasma thermal current (which scales the sheath current), the magnetic field (which limits the sheath current), and the emitter current. If the floating potential were close to the emitter energy, then we would need to define the emitter to emit a spectrum of particle energies to simulate the fraction of emitted electrons that return to the spacecraft.

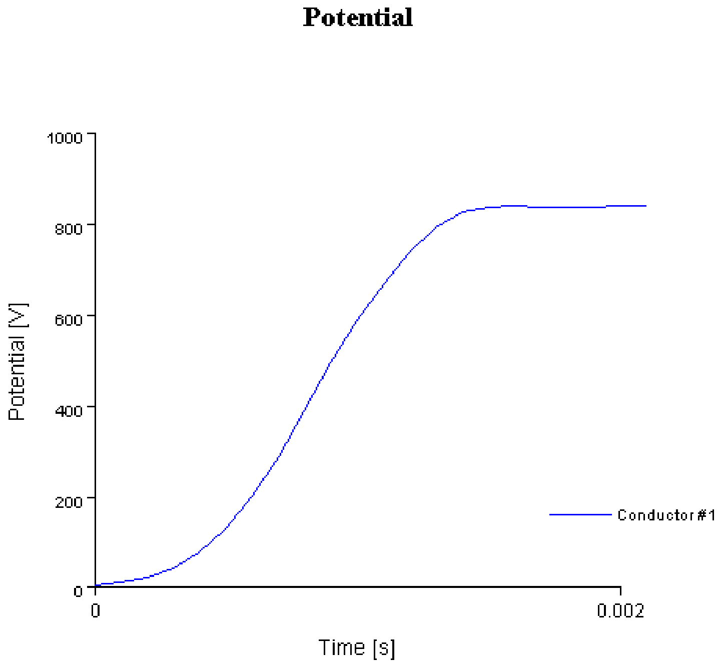


Figure 157. Potential versus Time for the Emitter Example.

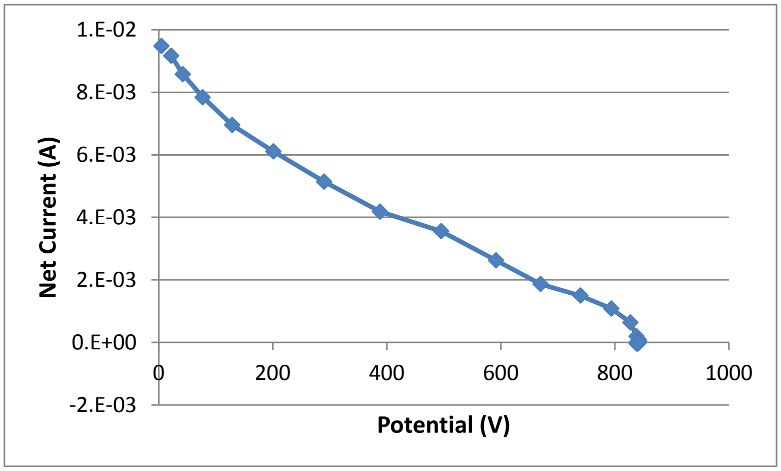


Figure 158. Net Current versus Potential for the Emitter Problem.

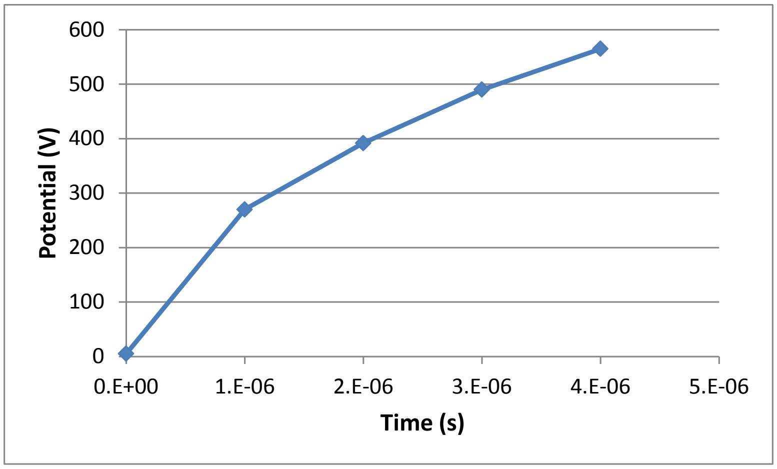


Figure 159. Charging Dynamics with the Stabilizing Current Derivatives Set to Zero.

COMMON GOTCHAS AND FREQUENTLY ASKED QUESTIONS

Caveats

Generally, a “Potentials in Space” “Self-consistent with Ion Densities” computation is only done with a sizeable velocity. A finite velocity is not required, but if the velocity is small the user should carefully consider the appropriateness of the approach.

Computing space potentials self-consistently with ion densities requires ion densities throughout the computational space. Thus the ion should be tracked from the boundary of the problem and not from a sheath edge.

The analytic model of ions in the auroral environment is only applicable at very low densities.

The analytic model of plasma currents in a LEO environment is only applicable at very low densities.

Frequently Asked Questions

Question: *Nascap-2k* keeps dying before the end of the computation. I’ve run the same case three times to make sure it wasn’t a fluke. And it’s taking over four hours to run up to the point that it dies.

Answer: The following questions can help you diagnose the problem.

- Is there any message in the last output file? What is the code doing when it dies?
- Is there an error message on the console? Or in the prefix.log file?
- Are the results reasonable up until the point the code dies? (Do the space potentials look reasonable? Are the currents reasonable numbers? Is the chassis potential varying smoothly?) What is the first thing that looks strange? Once a solution goes bad, it generally won’t get better.
- How does it behave when you restart with the existing files?
- How does it behave when you use a very simple object, like a cube, to do the same problem?

Question: How do I see messages on the console? The command prompt window disappears before I can read it.

Answer: To run from a persistent window (so you can see the error messages), navigate to the **Program Files (x86)\Leidos or Program Files\Leidos** directory as appropriate, and with the shift key held down, right-click the **Nascap2k_4** folder and select “Open Command Prompt Here”. Then type `Nascap2k.bat` at the command prompt.

Question: Can I use my files from a previous version of *Nascap-2k*?

Answer: The ***prefix*Object.xml** and ***prefix*.grd** files are fully compatible. In general, ***prefix*Project.xml** files from previous versions can be used. Some new capabilities and name updates do not appear if an old project file is used. To gain the full capabilities, creation of a new project file is recommended. As two copies of *Nascap-2k* (using different files) can execute at the same time, it is easy enough to bring up one copy of the code using the old project file and another copy using a new blank project file and then transfer all the settings.

Question: Until last week I had no problems using *Nascap-2k*. Last week my PC's operating system was updated and now it crashes before it gets started.

Answer: The problem may be that Java 3D is not installed in the version of Java that you are using. Uninstall and reinstall Java 3D as described in Section 4.3.

Question: I get an error message that says, "Exception in thread 'main'
java.lang.NoClassDefFoundError: java/vecmath/Tuple3f
at com.maxwell.nascap.N2kMain.main(N2kMain.java)."

Answer: Your Java 3D is not installed properly. Uninstall and reinstall Java 3D as described in Section 4.3.

Question: When I start up, I get an error message that says, "No compatible device found."

Answer: Java 3D for OpenGL requires 32-bit color. To set the color quality, select "Display" on the "Control Panel" (on the **Start** menu) to bring up the **Display Properties** dialog box. Select the **Settings** tab to access the screen resolution and color quality.

Question: When I start up, I get an error message that says, "wglCreateContext Failed: The pixel format is invalid" or "java.lang.NullPointerException: Canvas3D: null GraphicsConfiguration."

Answer: Java 3D for OpenGL requires 16-bit Z buffering.

Question: When I clicked on the Run button on the Script tab, I get a dialog box labeled dgetf2 and a message about A(18,18) = -1.#IND00.

Answer: Something is wrong with the object; look for those red lines. A doubly defined surface element won't generate a red line, but will cause this type of trouble. A badly distorted surface element can also.

Question: I get a convergence failure in INEIMP message. What does this mean?

Answer: Something is wrong with the secondary electron emission material properties. The SEE Interactive Spacecraft Charging Handbook provides a convenient testbed for testing property sets or developing sets that will work.

If you cannot see what the problem is just by looking at the numbers, here is something you can try.

> First create a boring object with all the materials defined in the file. The easy way to do this is to open your object with *Object Toolkit*, specify new object (so your object disappears leaving the material definitions), create a 6 sided box, assign the various materials to surfaces of the box, and save out the box.
>
> Next run a one step charging calculation (new project). It may only be necessary to execute the first step or two. The calculation should fail in the same way.

If it does fail, delete the materials one by one from the end of the object file and repeat. It is important to start a clean project each time. (Actually it might be okay to keep the project file, but nothing else).

If the calculation does not fail, diff the original object file with the simple object file and look for differences in the material definitions.

Question: On the **Problem** tab, the “Potentials in Space” “Problem Type” is not available. What’s up?

Answer: The **Potentials in Space** computation requires a grid.

Question: On the **Problem** tab, nothing under the “Problem Type” is active.

Answer: Nothing is available until the object is loaded. Select “Load Object” on the **File** menu.

Question: How do I get the new object with a grid from *GridTool* to *Nascap-2k*?

Answer: For a grid created by *GridTool* to be read by *Nascap-2k*, the file needs to be where *Nascap-2k* expects it and to have the same prefix as the *Nascap-2k* project. Make sure to save the grid file to *Prefix*.grd in the *Nascap-2k* problem folder.

Question: Does *Nascap-2k* automatically see the grid once it’s been embedded, or does one need to input or do something else?

Answer: Actually, the *Nascap-2k* user interface sees the ***prefix*.grd** file. If the file is in the right place with the right name, the *Nascap-2k* **Problem** tab should give you a “Grid Status” of “Loaded.” However, the computational modules only see the results of having embedded the object in the grid. If you have not yet embedded the object in the grid, the code knows that it needs doing when you click the “Build Script” button on the **Script** tab to request a script to compute the potentials in space.

Question: My *GridTool* TreeView seems incorrect after adding an outer grid.

Answer: Save the grid. Exit and restart *GridTool*. Import your saved grid.

Question: I’m trying to run Case 2 of the “CHAWS” example. I’ve entered all the information, but when I click “Build Script” it says I have no species selected, but I really think I do.

Answer: See the bluish highlight in Figure 90 in Section 19.5 for an example of how it should look if a species is selected. Multiple species may be selected.

Species for each purpose are selected separately. The selections on the **Problem** tab determine which subtabs on the **Particle** tab are available. Species need to be selected on all available subtabs. It’s easy to miss one.

Question: I am running a LEO charging problem and my spacecraft doesn’t charge.

Answer: Did you specify any applied potentials? An object at uniform potential in low Earth orbit rapidly reaches a slightly negative potential.

Question: I edited the script file and saved it. I unchecked the "automatically overwrite files" checkbox and then clicked the "Run Script" button. My script was overwritten. What's up?

Answer: The "automatically overwrite files" checkbox refers to the input files to the computational modules, not to the script itself. The script file may be saved out and read in using the "Save Script" and "Load Script" choices on the **File** menu. The ***prefix*****Driver.xml** file is saved every time the "Run Script" button is clicked even if the checkbox is unchecked.

Question: I did a calculation and nothing appears on the **Results** tab.

Answer: The checkboxes along the left side of the tab indicate which quantities are plotted and which values are displayed. The plotted and displayed values are updated when the "Plot" button is clicked.

Alternatively, there may be nothing to plot. *Nascap-2k* keeps time histories of charging calculations and self-consistent iterations between space potentials and surface currents. The results of a single calculation of potentials in space and surface currents are not saved for display by the **Results** tab.

Question: I changed one of the parameters on the **Settings** subtab of the **Results** tab, and the change does not appear in my plot.

Answer: The change takes effect the next time the "Plot" button is clicked.

Question: I'm not able to do cut planes. Is that only available if there's a grid?

Answer: Cut planes are only available if space potentials have been calculated, which requires a grid.

Question: I tried to do a trajectory calculation and nothing happened. A monitor briefly appeared, but no lines appeared on the three-dimensional figure.

Answer: The code can only handle a reasonable number of trajectory segments and just stops when there are too many. This can lead to trajectory segments at the outer edge of the grid that don't get noticed. The same problem can occur when plotting particle locations. Use the "Tracking Limits" to constrain the region of space in which particles trajectories begin.

Alternatively, the cut plane can hide the trajectories.

Question: I am getting extra lines in the three-dimensional display on the **Results 3D** tab.

Answer: Four items to check are the following: (1) Check if the Z buffering is turned on. (2) Check for updated video drivers. (3) Check the version of OpenGL. Can you use an older or newer one? (4) Try an older or more recent version of Java 3D.

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APPENDICES

A. Files

Nascap-2k uses a large number of files for different purposes. This appendix describes the files associated with a project, the contents of the input and output text and XML files, and the files placed on the user's disk during installation.

Four of the computational modules, **Embed Object in Grid**, **Potentials in Space**, **Create Particles**, and **Track Particles** have input and output files. As the command executes, it first uses information on the various tabs to construct the text input file and write it to disk. Then it starts the computational module. The module reads the input file, executes using the parameters specified in the input file, and writes a text output file in addition to writing its results into the database. The contents of these files are described in Section A.2 of this appendix.

A.1 Files Associated with a Project

A *Nascap-2k* project always has an associated "*prefix*" (i.e., name of project) that is used to identify the files associated with the project. Table 36 describes the files that may be found. To re-create a project (e.g., to make a copy or re-create a corrupted database) requires only the ***prefix*Project.xml** and ***prefix*Object.xml** files and (if present) the ***prefix*.grd**, ***prefix*Photo.xml**, and ***prefix*.Plume.xml** files.

Table 36. Files Created and Used by *Nascap-2k*

FILE	CONTENTS
***prefix*.NBS**	Contains information about the bounding surface elements of the special elements and is needed to calculate electric fields in special elements and to display potentials in space.
***prefix*.NDB**	Main data file containing time independent information about the calculation.
***prefix*.NME**	Contains the potential solver finite-element matrices for special elements in grid *nn*. There is one such file for each grid containing special elements.
***prefix*.NTM**	Contains stored histories of spatial and surface properties.
prefix*.NPT*nn	Contains present location, velocity, and other properties of macroparticles.
***prefix*.grd**	ASCII file generated by *GridTool* that contains the grid information
***prefix_n*_in.txt**	Automatically generated ASCII input file containing well-labeled project parameters whose values may be altered by the user.
***prefix_n*_out.txt**	ASCII output file created by a *Nascap-2k* module. The file contains a large amount of diagnostic information.
***prefix*Photo.xml**	Contains the description of the photoemission spectrum.
***prefix*Object.xml**	Contains the description of the object.
***prefix*Plume.xml**	Contains the plume map (ions and optionally neutral atoms) for any thrusters.
***prefix*Project.xml**	The project (xml) file. Contains all the information specified on the interface.
***prefix*.log**	Text file containing some of the information displayed in the console. Overwritten each time *Nascap-2k* is run.
ProjectDir.txt	Text file that points to the directory of the last project or object saved. *Nascap-2k* uses this as the starting directory for searching for an existing project or object or saving a new one.

A.2 Contents of Input Files

Nascap-2k is designed to perform a standard set of computations with minimal guidance from the user. More complex computations can be performed by editing the script and by editing the input files. When using edited input files, the “Automatically overwrite files” checkbox should be unchecked.

Each line of the input files consists of a keyword followed by a value. Keywords can be one or two words. The value can be one or more real numbers, an integer, or a text string, depending on the keyword. A comment can follow. The keywords “Comment” and “Remark” indicate lines that are to be ignored. The keyword “End” specifies the end of the file. Table 37 through Table 40 list the keywords and the tabs from which the associated values are determined. In addition, the tables provide commentary for many of the keywords. The simplest way to generate a valid input file is to edit an automatically generated one.

Table 37. Contents of Input File for Embed Object in Grid Module

KEYWORD	COMMENTS
Prefix	Define the file prefix for this run. (Required.)
Diagnostics	Generate a large amount of diagnostic output.
Echo	Echo the neutral file.
Noecho	Do not echo the neutral file. (Default.)
Noprocess	Stop before generating any matrix elements.
OffDiag	Suppress off-diagonal matrix elements between surface elements.
Process *ix jy kz* Grid *igrid*	Proceed as expeditiously as possible to process the requested special element (for diagnostic purposes). If any of *ix*, *jy*, or *kz* is zero, process all of grid *igrid*.

Table 38. Contents of Input File for Potentials in Space Module

<table>
<tr><th>KEYWORD</th><th>TAB</th><th>COMMENTS</th></tr>
<tr><td>Run</td><td>None</td><td>Default value is “New” for “Iteration” attribute “0” and “Continue” for other iteration values.</td></tr>
<tr><td>Solution_Mix</td><td>Potential</td><td>The value is labeled fraction old potential and varies for different input files. The “Iteration” attribute provides the correspondence with the table on the tab. If the “Iteration” attribute is “0,” a value of 0.0 is generated.</td></tr>
<tr><td>Temperature</td><td>Environment</td><td>Temperature of the plasma</td></tr>
<tr><td>Debye</td><td>Environment</td><td>Debye length of the plama</td></tr>
<tr><td>Density</td><td>Environment</td><td>Number density of the plasma</td></tr>
<tr><td>Objvel</td><td>Environment</td><td>Three values for the x, y, and z velocity components.</td></tr>
<tr><td>Problem</td><td>Potential</td><td>Charge density model. The correspondence between the values on the tab and the keyword argument are as follows:
<table>
<tr><th>Value on tab</th><th>Keyword in file</th></tr>
<tr><td>Laplace</td><td>Laplace</td></tr>
<tr><td>Linear</td><td>Linear</td></tr>
<tr><td>Non-linear</td><td>Non_Linear</td></tr>
<tr><td>Frozen ion</td><td>Frozen_Ion</td></tr>
<tr><td>Barometric</td><td>Barometric</td></tr>
<tr><td>Full trajectory ions</td><td>Traj_Ion</td></tr>
<tr><td>Plume ion density</td><td>Plume</td></tr>
<tr><td>Hybrid PIC</td><td>Track_Ion</td></tr>
<tr><td>Full PIC</td><td>Explicit</td></tr>
<tr><td>Not on tab</td><td>Special</td></tr>
<tr><td>Not on tab</td><td>Sheath_Wake</td></tr>
<tr><td>Not on tab</td><td>Old_Track_Ion</td></tr>
</table></td></tr>
<tr><td>Rmass</td><td>Potential</td><td>Mass used for geometric wake calculations.</td></tr>
<tr><td>RmsMin</td><td>Potential</td><td>Root mean square error below which the potential is considered converged.</td></tr>
<tr><td>Wake</td><td>Potential</td><td>If “Wake” is “On” and “Run” is “New,” do a geometric wake calculation. Otherwise, don’t.</td></tr>
<tr><td>TIon</td><td>Environment</td><td>Temperature used for wake calculation.</td></tr>
<tr><td>Conv_Effect</td><td>Advanced</td><td>Only relevant for “Non-linear” space charge density formula. If “On,” include the convergence factor in the formula. If “Off,” don’t.</td></tr>
<tr><td>DebLim</td><td>Advanced</td><td>The number of Debye screening lengths allowed per volume element.</td></tr>
<tr><td>Debye_Scale</td><td>Advanced</td><td>Allowed values are “Local” and “Primary.”</td></tr>
<tr><td>BField</td><td>Environment</td><td>Three values specifying the three components.</td></tr>
<tr><td>Min_Density</td><td>Potential</td><td>Minimum density.</td></tr>
<tr><td>Boundary</td><td>None</td><td>Sets boundary condition on grid boundary. Allowed values are “Zero,” “Monopole,” and “Debye.” Module assumes “Monopole” for “Laplace” charge density model, “Debye” for “Linear” and “Non-linear” charge density models, and “Zero” otherwise. To change the default behavior, “Boundary” keyword must follow “Problem” keyword.</td></tr>
<tr><td>Save_Interval</td><td>Advanced</td><td>Keyword is followed by two integer values giving the frequency of saving and at which iteration saving should start.</td></tr>
<tr><td>Diag Final</td><td>Advanced</td><td>Print final potential values.</td></tr>
<tr><td>Diag Init</td><td>Advanced</td><td>Print initial potential values.</td></tr>
</table>

Table 38. Contents of Input File for Potentials in Space Module (continued)

KEYWORD	TAB	COMMENTS
Diag Interface	Advanced	Integer value that indicates level of diagnostics information output regarding grid interface details.
Diag Matrix	Advanced	
Diag Scg	Advanced	Integer value that indicates level of diagnostics information output regarding scaled conjugate gradient calculations.
Diag Screen	Advanced	Integer value that indicates level of diagnostics information output regarding space charge screening.
Diag Wake	Advanced	Integer value that indicates level of diagnostics information output regarding geometric wake calculations.
GridHigh	Advanced	Maximum grid number defining the range of grids in which potentials are to be computed.
GridLow	Advanced	Minimum grid number defining the range of grids in which potentials are to be computed.
MaxItc	Advanced	The maximum number of minor iterations within each conjugate gradient solution.
MaxIts	Advanced	The maximum number of major or "space charge" potential iterations to be performed.
NAdd	Advanced	Number of extra vertices to add to compute object shadow for geometric wake calculation.
NPhi	Advanced	Number of polar angle divisions in geometric wake calculation.
NTheta	Advanced	Number of azimuthal angle divisions in geometric wake calculation.
PotCon	Advanced	The number of orders of magnitude that the RDotR parameter drops within each conjugate gradient solution before it is considered converged.
RdrMin	Advanced	The value of the "RDotR" parameter below which the potential is considered converged.
Time Start	None	Multiply the conductor potential by a factor of $\left(1-\exp\left(-\frac{t-t_{start}}{t_{rise}}\right)\right)\exp\left(-\frac{t-t_{start}}{t_{fall}}\right)$ where t is the time in seconds before computing space potentials.
Time Rise	None	
Time Fall	None	
Timer	Advanced	Integer value that indicates the frequency at which the time since the computer was last rebooted is given in output file.
Algorithm	None	Not used.

Table 39. Contents of Input File for Create Particles Module

KEYWORD	TAB	COMMENTS
Part_Type	Particles	Allowed values are “Default,” “Sheath,” “Contour,” “B_field,” “Boundary,” “CEX,” “Inject,” “Detector”, “Emitter”, “External.” “Default” specifies a uniform distribution. “Inject” macroparticles require the timestep as an additional argument.
Sheath_Pot	Particles	Sheath potential.
N_Zone	Particles	Number per boundary surface element.
Cut_Plane	Particles	The keyword is followed by “X,” “Y,” or “Z” specifying the cut plane direction and a real number specifying the cut plane location in grid coordinates. (1,1,1) is the lowest corner of the grid.
External_File	Particles	Filename.
External_Type	Particles	Allowed values are “Formatted” and “Unformatted.”
B_Field	Environment	Three components of ambient magnetic field.
TIon	Environment	Initial thermal energy of particles. Also plasma temperature used for thermal distribution.
RhoIon	Environment	Plasma density used to generate particles.
VRam	Environment	Three components of spacecraft velocity.
Species	Environment	Keyword followed by a string specifying the species name and two real numbers specifying the species charge in coulombs and mass in either AUM or kilograms. This keyword must follow “Part Type” keyword.
Delete	None	Delete the species whose name follows the keyword. To delete all species, specify “All.”
Pvx	Advanced	Fraction of distribution in each orientation that each particle represents.
Pvy	Advanced	Fraction of distribution in each orientation that each particle represents.
Pvz	Advanced	Fraction of distribution in each orientation that each particle represents.
Random	None	No argument. Create seed for random number generator from date and time.
Diag_Partgen	Advanced	Integer giving level of diagnostics information output during particle generation.
Diag_Dynalib	Advanced	Integer giving level of diagnostics information output.
Timer	Advanced	Frequency at which cpu time is given in output file.
Subdivision	Advanced	A single integer and the string “ALL” specify the default ratio. Additional subdivision lines can be used to specify finer (or coarser) resolution. A line with the keyword “Subdivision” and four integers is understood to give (1) the ratio by which to subdivide boundary elements before generating particles at centers and (2) the low index corner of the boundary element. Only for Boundary type.
Emitter_Name or Detector_Name	Particles	Name of emitter or detector.
Speed_Values	Advanced	Integer giving the number of speed values and two real numbers giving the minimum and maximum speeds in meters/sec.
Theta_Values	Advanced	Integer giving the number of polar angle values and two real numbers giving the minimum and maximum polar angles in radians.
Phi_Values	Advanced	Number of azimuthal values.
Num_Locations	Advanced	Number of locations on each surface element of the emitter or detector at which to create particles.
Current_Density	Particles	Emitted current density.
Grid	None	Generate particles in specified grid. If no “Grid” keyword appears, particles are generated in all grids. Multiple lines are needed to specify multiple grids.
Split	Particles	Split particles unless followed by keyword “Off,” “No,” or “False.” If followed by the keyword “Skip” and integers follow that, particles in the grids specified by the integers are *not* split.

Table 40. Contents of Input File for Track Particles Module

KEYWORD	TAB	COMMENTS
Process	Problem or Results 3D	Available value are “Traj_Charge” for self-consistent with ion trajectories, “Space_Charge” for time-dependent problems, “Implicit” for time-dependent problems in which the charge is to be saved at every substep, “Plot_Particles” for viewing particle locations, and “Trajectories” to view trajectories or compute surface currents.
B_Field	Environment	Three components of the ambient magnetic field.
Track_Time	Particles	Tracking time per timestep.
Species	Particles	Name of species to be tracked. Multiple “Species” keywords can be present.
Max_Step	Particles	Maximum number of substeps.
Mix	Potentials	Fraction old density.
Dx_Max	Advanced	Distance a particle can go in one substep (in local mesh units).
Save_Interval	Advanced	Keyword is followed by two integer values giving the frequency of saving and at which iteration saving should start.
X_Limit, Y_Limit, Z_Limit	Advanced	Only track particles whose initial location begins within the specified region. Location given in grid units where (1,1,1) is the lowest corner of the grid.
X_Plot_Limit, Y_Plot_Limit, Z_Plot_Limit	Particles & Advanced	Limit particle tracking to specified region. Location given in grid units where (1,1,1) is the lowest corner of the grid.
Save_Interval	Advanced	Keyword is followed by two integer values giving the frequency of saving and at which iteration saving should start.
Diag_Tracker	Advanced	Integer giving level of diagnostics information output during particle generation.
Diag_Dynalib	Advanced	Integer giving level of diagnostics information output.
Timer	Advanced	Frequency at which cpu time is given in output file.
UpdateTime		Change the time by the tracking time at the end of execution.
Split	Advanced	Split particles on entering subgrid unless first argument is “Off,” “No,” or “False.” If the first argument is “Skip” and integers follow, particles entering the grids specified by the integers are *not* split. If the first argument is “MinTemp,” particles with temperatures below the value given in the second argument are *not* split.
Track_Electrons	None	Save volume charge and current to database using electron keywords.
Random	None	No argument. Create seed for random number generator from date and time.
Print_Track	None	Include position, potential, and volume charge density at each timestep in the output file. Can be used with particles defined in an external file to generate potentials along a line.

A.3 Contents of Output Files

A.3.1 Embed Object in Grid

The **Embed Object in Grid** module produces voluminous output. Normally, this output is of no concern to the user. However, if an error occurs during processing (such as a limit being exceeded) or potential solutions look strange or fail to converge, the **n2kdyn_out.txt** file may hold the key to the problem. The following sections describe this output file in a way that guides an ordinary user to find error indicators that may be meaningful.

A.3.1.1 Input Echo

The file begins with echo of the input file. *Nascap-2k* creates an input file with the project prefix followed by an end line. It is possible to limit processing to a specific volume element and request an increased level of diagnostic output. This is not likely to be helpful to most users.

A.3.1.2 Grid Echo

Following the input echo, the output echoes the grid file. This should correspond to the grid as defined in *GridTool*, and reflect the correct object dimensions and centering.

A.3.1.3 Grid Analysis and Special Element Determination

Next, the code cycles through the grids to classify each node as interior or exterior, and to classify each volume element of the volume as filled, empty, or “Special.” A volume element is filled if (a) it is interior to the object; (b) it belongs to a child (subdivided) grid; or (c) all eight of its nodes are interior. A volume element is “Special” if it (a) contains a surface centroid; (b) contains a surface node; or (c) contains at least one interior node and at least one exterior node. The limit on the number of “Special” elements is 8191, which is roughly double the 4095 limit on the number of object surfaces. The output shows the accumulation of special elements grid by grid, so the user can determine which grid is contributing an excess number.

The first part of this process for each grid is the node interior/exterior determination. To do this, intersections of grid lines and surfaces are found. Usually, a grid line passes through a surface from exterior to interior, and then through another surface from interior to exterior. Ambiguities may occur, for example when a grid line is nearly coplanar with an object surface. However, as each node is traversed by grid lines in three directions, an unambiguous determination can virtually always be made. The user may see diagnostic messages reflecting this process. Usually no action is required unless more serious errors occur later, in which case moving the object so that surfaces are not coplanar with grid lines may help.

In this process we fill an array with a dimension $(2N_1\text{-}1)(2N_2\text{-}1) < 9000$, where (N_1,N_2) are a pair of Fortran grid dimensions (Nx,Ny), (Ny,Nz), or (Nz,Nx). (The Fortran dimensions are one unit greater than the values entered in *GridTool*.) This places a limit on products of pairs of grid dimensions of about 2250. So, for example, a grid of (41, 51, 7) is allowed, but a grid of (47, 51, 5) is not. If a grid does not satisfy this requirement, the “Too many grid lines” message appears, and the code exits.

A.3.1.4 Special Element Matrix Construction

Having identified the special elements, the code proceeds grid by grid and volume element by volume element to analyze the special elements and to construct their bounding surfaces and finite-element matrices. That is, the code must find the pieces of surface elements that lie within the volume element, relate the potentials on those surface elements to the unique potential iteration scheme for the object surface, and construct a volume potential interpolation scheme based on those surfaces and on the free surfaces of the surface element. Some output is written for each special element. For example:

```
EltMat = XYZ0 =  3.0  1.0  27.0 Grid 8
 CCLTR3 successfully formed  3 triangles.
 CCLTR3 successfully formed  3 triangles.
 Boundary Surface Structure for special cell 2816 has 1309 words.
 Dimension reduced from 62 to 62
```

is a typical error-free output. The “3.0 1.0 27.0” indicates the location of the volume element within grid 8. The lowest indexed corner of the grid is “1.0 1.0 1.0.” CCLTR3 is one of several routines that provides harmless diagnostic output. Other such routines include CRNSUB and ADLNOD. The size of the “Boundary Surface Structure” may range from a few hundred to a few thousand words, and indicates the complexity of the special element. If volume elements appear with the size of this structure larger than about 3000, additional subdivision should be considered to reduce complexity in that region. Other types of usually benign output include:

```
EltMat = XYZ0 =  31.0  19.0  5.0 Grid 9
   SrfBpl - no surfaces and all corners filled
  Error encountered at index= 6817, grid 9 XYZ0=  31.0  19.0  5.0
   Zone will be marked as filled.
EltMat = XYZ0 =  2.0  1.0  3.0 Grid 11
 EmptMt called: Index=  52 KeyNo= 5838 Filled=FFFFFFFF
 Revising Ltbl to show empty cube element.
```

These indicate volume elements that, for some reason, have been incorrectly identified as special. In the first case the volume element was reclassified as filled and in the second as empty. Such reclassification may be the result of the code moving nodes by small amounts in order to simplify the local matrix structure. Other types of benign errors may appear as well. Nonetheless, if the potential solution shows errors in these regions, these error messages may be indicative of a problem that can be resolved through minor modifications of object definition, grid structure (or additional subdivision), or object placement in grid.

Other errors strongly indicate that the code was unable to correctly analyze the volume element. While fatal errors are rare, incorrectly analyzed volume elements may be harmless or may cause local errors in the potential solution. Such local errors may cause poor convergence (or non-convergence) of the entire potential solution. Additional subdivision is the usual remedy. Some examples are:

```
EltMat = XYZ0 =  11.0  15.0  8.0 Grid 3
 GetCen - unable to find centroid
 Error - Path with undetermined sense. Assume Counter-Clockwise.
 Boundary Surface Structure for special cell 507 has 2943 words.
 Dimension reduced from 90 to 90
```

This volume element has two problems, as well as a fairly large boundary surface structure. Possibly an object corner pierces an edge leaving both nodes free, or pierces a face leaving its four nodes free.

```
EltMat = XYZ0 =  18.0  17.0  9.0 Grid 3
  DogNut Warning - Non-monotonicity in counter-clockwise path point thetas.
  DogNut Warning - Non-monotonicity in counter-clockwise path point thetas.
  DogNut Warning - Non-monotonicity in counter-clockwise path point thetas.
  DogNut Warning - Non-monotonicity in counter-clockwise path point thetas.
  DogNut Warning - Non-monotonicity in counter-clockwise path point thetas.
 Warning - DogTri - got stuck at dead-end
 Warning - Error in CCLTr3 - NTri= 5
 Boundary Surface Structure for special cell 597 has 1526 words.
```

This type of error is usually associated with a boom or strut piercing one or more faces of a volume element. Try making the strut thicker or have it lie along a grid line.

```
EltMat = XYZ0 =  7.0  10.0  7.0 Grid 9
 Warning - Error in CCLTr3 - NTri= 0
 Error - AddSeg could not add triangle for  1 2
 Error - AddSeg could not add triangle for  2 3
 Error - AddSeg could not add triangle for  3 4
 Error - AddSeg could not add triangle for  4 1
 Boundary Surface Structure for special cell 2373 has  807 words.
```

This error indicates serious failure of the analysis. The volume element appears to have had multiple surfaces cutting through volume element corners at slant angles. There were four volume elements with similar errors. In this case, subdivision cured the errors for all four volume elements.

A.3.2 Potentials in Space

The output file from the **Potentials in Space** module is used mainly to determine whether the potential solution has adequately converged and, if not, to help determine the region of space that is causing the problem. It also can be used to verify that the input to the module is correct and/or has been correctly interpreted.

A.3.2.1 Input Echo

The first section echoes the input and should be virtually identical to the input file. Following the input echo, the plasma density, temperature, and Debye length are listed, followed by parameters relating to spacecraft motion, such as the ram energy, ion thermal velocity, and Mach number.

A.3.2.2 Grid Pairs

The section headed "Final grid pairs list …" is an analysis of the grid structure showing pairs of grid having common faces that must be interfaced. For example, the following list

```
Final grid pairs list ...
   #      Pairs       IFaces
   1      1:  2       1  1  1  1  1  0
   2      1:  3       1  1  1  1  0  0
   3      1:  4       1  1  1  1  0  1
   4      1:  9       0  1  0  1  0  0
   5      2:  3       0  0  0  0  1  0
   6      2:  5       1  1  1  1  1  0
```

```
  7       2:  6        1  1  1  1  1  0
  8       2:  7        1  1  1  1  1  0
  9       2:  8        1  1  1  1  1  0
 10       2:  9        0  0  0  0  1  0
 11       2: 10        1  1  1  1  1  0
 12       2: 11        1  1  1  1  1  0
 13       2: 12        1  1  1  1  1  0
 14       2: 13        1  1  1  1  1  0
 15       3:  4        0  0  0  0  1  0
 16       3:  9        1  0  1  0  0  1
 17       5:  9        0  0  0  0  1  0
 18       6:  9        0  0  0  0  1  0
 19       7:  9        0  0  0  0  1  0
 20       8:  9        0  0  0  0  1  0
 21       9: 10        0  0  0  0  0  1
 22       9: 11        0  0  0  0  0  1
 23       9: 12        0  0  0  0  0  1
```

shows that grid 2 interfaces with grid 1 on all its faces but +Z, grid 4 interfaces with grid 1 on all its faces but –Z, and grid 3 interfaces with grid 1 on its ±X and ±Y faces, with grid 2 on its –Z face (the +Z face of grid 2), and with grid 4 on its +Z face (the –Z face of grid 4).

A.3.2.3 Wake Calculation

If a wake calculation is taking place, it is described by the section containing words such as “A2Driv” and “GiComp.”

A.3.2.4 Preparatory Section

Preparation for the potential calculation takes place in the “PSprep” section, which repeats many of the parameters extracted from the input and the database. It includes the grid spacing for the various grids, recommended sheath potentials in those grids, conductor potentials, and magnetically induced electric field.

Of particular note are the sheath boundary potentials for non-linear charge density calculations and the barometric potentials for frozen ion charge density calculations. Lines similar to the following appear in the output file for these types of problems.

```
Sheath boundary potentials:
 Grid # 1 Ymesh= 1.000000 meters. SthPot= 1.485810 volts.
 Grid # 2 Ymesh= 0.500000 meters. SthPot= 0.589644 volts.
 Grid # 3 Ymesh= 0.250000 meters. SthPot= 0.234000 volts.
 Grid # 4 Ymesh= 0.125000 meters. SthPot= 0.092863 volts.

Frozen ions - for YMesh= 1.000 Phi1=  -45.1773
Frozen ions - for YMesh= 0.500 Phi1=  -11.2943
Frozen ions - for YMesh= 0.250 Phi1=   -2.8236
Frozen ions - for YMesh= 0.125 Phi1=   -0.7053
```

The use of the sheath boundary potential and the way in which it is calculated is described in Section 15.1. The barometric potential used in computing the charge density for frozen ion calculations is defined in Section 14.1.

A.3.2.5 Potential Solution

The potential solution solves for the potential, electric field, and space charge in the volume surrounding the spacecraft. It consists of a sequence of steps in which the space charge is linearized about the current trial solution, and the resulting linear problem is solved (to a limited degree of convergence) by a conjugate gradient technique. Surface element potentials, electric fields, and areas are output for each linearization.

In the linear (conjugate gradient) portion of the potential solution, the default convergence requirement is that the error parameter *rdotr* decrease (by default) by two orders of magnitude. The following lines containing “rdotr” are selected out from three space-charge iterations.

```
PSscg - after initializing U() and R(), initial rdotr=  7.618D+02
   rdotr0, rdrlas, rdotr =  7.618D+02 7.618E+02 5.346D+02
   rdotr0, rdrlas, rdotr =  7.618D+02 5.346E+02 7.265D+01
   rdotr0, rdrlas, rdotr =  7.618D+02 7.265E+01 9.247D+01
   rdotr0, rdrlas, rdotr =  7.618D+02 9.247E+01 5.176D+01
   rdotr0, rdrlas, rdotr =  7.618D+02 5.176E+01 3.084D+01
   rdotr0, rdrlas, rdotr =  7.618D+02 3.084E+01 2.126D+01
   rdotr0, rdrlas, rdotr =  7.618D+02 2.126E+01 1.341D+01
   rdotr0, rdrlas, rdotr =  7.618D+02 1.341E+01 1.010D+01
   rdotr0, rdrlas, rdotr =  7.618D+02 1.010E+01 6.615D+00
PSscg -- converged after  9 iterations. rdotr= 6.615D+00
PSscg - after initializing U() and R(), initial rdotr=  6.886D+00
   rdotr0, rdrlas, rdotr =  6.886D+00 6.886E+00 3.478D+00
   rdotr0, rdrlas, rdotr =  6.886D+00 3.478E+00 2.604D+00
   rdotr0, rdrlas, rdotr =  6.886D+00 2.604E+00 1.865D+00
   rdotr0, rdrlas, rdotr =  6.886D+00 1.865E+00 1.764D+00
   rdotr0, rdrlas, rdotr =  6.886D+00 1.764E+00 1.002D+00
   rdotr0, rdrlas, rdotr =  6.886D+00 1.002E+00 7.740D-01
   rdotr0, rdrlas, rdotr =  6.886D+00 7.740E-01 4.800D-01
   rdotr0, rdrlas, rdotr =  6.886D+00 4.800E-01 5.004D-01
   rdotr0, rdrlas, rdotr =  6.886D+00 5.004E-01 2.056D-01
   rdotr0, rdrlas, rdotr =  6.886D+00 2.056E-01 1.321D-01
   rdotr0, rdrlas, rdotr =  6.886D+00 1.321E-01 7.751D-02
   rdotr0, rdrlas, rdotr =  6.886D+00 7.751E-02 3.251D-02
PSscg -- converged after 12 iterations. rdotr= 3.251D-02
PSscg - after initializing U() and R(), initial rdotr=  1.837D-01
   rdotr0, rdrlas, rdotr =  1.837D-01 1.837E-01 9.941D-02
   rdotr0, rdrlas, rdotr =  1.837D-01 9.941E-02 2.142D-02
   rdotr0, rdrlas, rdotr =  1.837D-01 2.142E-02 1.407D-02
   rdotr0, rdrlas, rdotr =  1.837D-01 1.407E-02 1.295D-02
   rdotr0, rdrlas, rdotr =  1.837D-01 1.295E-02 1.185D-02
   rdotr0, rdrlas, rdotr =  1.837D-01 1.185E-02 1.173D-02
   rdotr0, rdrlas, rdotr =  1.837D-01 1.173E-02 8.420D-03
   rdotr0, rdrlas, rdotr =  1.837D-01 8.420E-03 4.378D-03
   rdotr0, rdrlas, rdotr =  1.837D-01 4.378E-03 2.904D-03
   rdotr0, rdrlas, rdotr =  1.837D-01 2.904E-03 2.105D-03
   rdotr0, rdrlas, rdotr =  1.837D-01 2.105E-03 1.096D-03
PSscg -- converged after 11 iterations. rdotr= 1.096D-03
```

The above lines illustrate the convergence from *rdotr0* through the final *rdotr* through three space-charge iterations. In this well-behaved problem, the parameter *rdotr* decreases monotonically within each space-charge iteration, and the parameter *rdotr0* (or *initial rdotr*) decreases monotonically from each space-charge iteration to the next. However, there is no mathematical requirement for this monotonic behaviour, and highly non-monotonic behavior is commonly observed.

Another measure of convergence from one space-charge iteration to the next is the “rms error,” which measures the difference in potentials and electric fields from the previous linear solution to the current one. The following lines containing “rms” are selected from three space-charge iterations:

```
RMS Error for Grid # 1 =  8.6822E-02
RMS Error for Grid # 2 =  2.8675E-01
RMS Error for Grid # 3 =  2.1929E-01
RMS Error for Grid # 4 =  1.6132E-01
RMS Error for Grid # 5 =  1.3876E-01
RMS Error for Grid # 6 =  1.8677E-01
RMS Error for Grid # 7 =  1.2993E-01
RMS Error for Grid # 8 =  1.3343E-01
RMS Error for Grid # 9 =  1.2599E-01
RMS Error for Grid # 10 =  1.2674E-01
RMS Error for Grid # 11 =  1.5381E-01
RMS Error for Grid # 12 =  1.1919E-01
RMS Error for Grid # 13 =  1.7715E-01
PSMAIN -- space charge iter=  1 rmserr= 1.8358E-01
RMS Error for Grid # 1 =  6.5594E-03
RMS Error for Grid # 2 =  5.1048E-02
RMS Error for Grid # 3 =  3.4787E-02
RMS Error for Grid # 4 =  1.4695E-02
RMS Error for Grid # 5 =  3.6307E-02
RMS Error for Grid # 6 =  2.7121E-02
RMS Error for Grid # 7 =  3.3636E-02
RMS Error for Grid # 8 =  1.7829E-02
RMS Error for Grid # 9 =  4.5233E-02
RMS Error for Grid # 10 =  2.6144E-02
RMS Error for Grid # 11 =  3.6491E-02
RMS Error for Grid # 12 =  1.8405E-02
RMS Error for Grid # 13 =  2.9253E-02
PSMAIN -- space charge iter=  2 rmserr= 3.4853E-02
RMS Error for Grid # 1 =  2.2271E-03
RMS Error for Grid # 2 =  5.1493E-03
RMS Error for Grid # 3 =  4.3516E-03
RMS Error for Grid # 4 =  3.7434E-03
RMS Error for Grid # 5 =  3.0820E-03
RMS Error for Grid # 6 =  7.0575E-03
RMS Error for Grid # 7 =  2.5721E-03
RMS Error for Grid # 8 =  2.4259E-03
RMS Error for Grid # 9 =  7.1831E-03
RMS Error for Grid # 10 =  2.1519E-03
RMS Error for Grid # 11 =  2.9523E-03
RMS Error for Grid # 12 =  2.3842E-03
RMS Error for Grid # 13 =  8.1659E-03
PSMAIN -- space charge iter=  3 rmserr= 4.8034E-03
PSMAIN -- converged, rmserr= 4.8034E-03
```

Again, in this well-behaved problem the *rmserr* parameter decreases monotonically, although there is no mathematical requirement that it do so. The reason for including the “*RMS Error for Grid …*” values is so that, in case of non-convergence, it may be possible to identify the grid that is failing to converge and to resolve the problem by further subdivision of some portion of that grid.

A.3.2.6 Potential Text Output File

If the potential solution has converged (or completed the allotted effort without diverging), the output concludes with a lengthy listing of the potential and field values for the central XY planes of each grid. A sample output for a 5×5×37 grid is as follows:

```
   POT_Grid DATA FOR GRID  8 SLICE Z = 19

      -->X IS HORIZONTAL, Y IS VERTICAL<--

    1.E 1 *  -0.27        0.00        0.90        0.46        0.01
  5 1.E 1 *  -0.09 -0.23  0.00  0.00 -0.06  1.25 -0.03  0.70 -0.01  0.21
    1.E 1 *  -0.16       -0.25        0.00        0.55        0.16
  4 1.E 1 *  -0.09 -0.24 -0.10 -0.25  0.00  0.00 -0.05  1.93 -0.01  0.33
    1.E 1 *  -0.15       -0.11       -0.39       -0.26        0.11
  3 1.E 1 *  -0.08 -0.25 -0.09 -0.23 -0.10 -0.20 -0.05  1.96 -0.02  0.45
    1.E 1 *  -0.03       -0.01        0.04       -0.18        0.16
  2 1.E 1 *  -0.08 -0.27 -0.09 -0.25 -0.09  0.00 -0.06  1.58 -0.02  0.66
    1.E 1 *   0.02        0.04        0.05        0.10        0.41
  1 1.E 1 *  -0.08 -0.29 -0.09 -0.26 -0.10 -0.32 -0.10  1.12 -0.03  0.87
               1           2           3           4           5
```

The numbers 1 through 5 at the bottom and left are the x and y node indices, respectively. The value preceding the asterisk (here all values of 1.E 1) is a power-of-ten multiplier to be applied to the line. On the lines having y indices, each x-index is represented by a pair of numbers giving the node's potential and x-component of potential gradient. The y-components of potential gradient appear on the line above. For example, the node (1,1) has V=-0.8 V, E_x=+2.9 V/m and E_y =-0.2 V/m. (Note that potential gradient is the negative of electric field.) Interior nodes have all values zero, so, in this example, node (3,4) may be an interior node.

A.3.2.7 Conclusion

An example of a normal conclusion of the potential solver output file follows:

```
     CPV Data , NCond =  1
     1   -1.6220E+00
 About to close input - unit 5

End Potential Solver.
 About to return from PSMAIN
```

If the file ends in any other way, the calculation did not conclude properly.

A.3.3 Create Particles

Output from the **Create Particles** module generator varies somewhat depending on the type of particle distribution being generated and the particle's intended purpose. The example being followed here generates electron macroparticles for space charge (Full PIC). We show differences for particles generated for visualization under control of an external file. Differences between these and other types of particle generation should be fairly apparent.

Note that each run generates only one species of particle. If multiple species are requested, there are multiple input and output files.

A.3.3.1 Initialization and Input

The output file begins with a welcome followed by a list of recognized keywords with syntaxes and meanings. When the "PREFIX" input line is found, the database is opened and the grid structure is enumerated. Remaining input lines are then processed. When the "END" line is encountered, a summary of the environment and available species is given. This summary appears as follows:

```
PGInpu: Particle type is SHEATH
 PGInpu: DebLim= 2.00 Debye,Temp,Dens = 1.0520E-02 1.0000E-01 4.9938E+10
 PGInpu: TIon,RhoIon= 1.0000E-01 5.0000E+10 VRam= 0.0000E+00 0.0000E+00 0.0000E+00
 PGInpu: sheath boundary potential=   4.3440 volts.
     Cut plane: Z=   9.00
     B Field:  0.00E+00 4.00E-05 0.00E+00
     Energy:  1.00E+00 NZone= 1
 PGInpu: Object velocity (m/s) =    0.00   0.00   0.00
 PGInpu: lunout, idiag, itimer=  6  1  1

PGInpu: total of 4 species defined.
  ISpeci Name    Charge(coul) Mass(Kg)
    1  OXYGENPL  1.6020E-19  2.6569E-26
    2  ELECTRON  -1.6020E-19  9.1097E-31
    3  OXYGEN   1.6020E-19  2.6569E-26
    4  ELECTRPL  -1.6020E-19  9.1097E-31
```

For some choices of particle type, some lines do not appear. All the species defined in the database are listed. Execution of **Create Particles** is how species specified in the user interface are added to the database. Note the “PL” suffix on two of the species. The suffix indicates that this is an added version of the species to be used only for plotting. The “PL” suffix is generated automatically by the *Nascap-2k* user interface.

A.3.3.2 Particle Generation

The line

```
      PGInpu: loop over grids 1 to 8
```

signifies the beginning of particle generation. It is followed by lines similar to the following:

```
GenPa2: end of grid # 1 found  3878 OXYGEN  particles. 1 pages written to disk.
 ***TIMER*** Total Elapsed User Time =257977.156 Seconds.
GenPa2: end of grid # 2 found  6020 OXYGEN  particles. 1 pages written to disk.
 ***TIMER*** Total Elapsed User Time =257977.188 Seconds.
GenPa2: end of grid # 3 found  8072 OXYGEN  particles. 1 pages written to disk.
```

Particles are grouped into batches of 10,000, referred to as pages. When a page of particles has been created, it is written to disk.

In the case that particles are read from an external file, the file is read and echoed as the particles are created:

```
LOCATION  1.59 1.1 0.0
 DIRECTION -1 0 0
 ENERGY 4.5
 LOCATION  1.59 1.0 0.0
 DIRECTION -1 0 0
 ENERGY 4.5
 LOCATION  1.59 0.9 0.0
 DIRECTION -1 0 0
 ENERGY 4.5

END

 GenPar: end of input. Found   35 OXYGENPL particles. 0 pages written to disk.
GenPar: found   35 OXYGENPL particles spanning  1 pages.
```

After looping through the grids, the following is written.

```
 GenPar: there are 345434 ELECTRON particles. The new ones are distributed as follows

  Grid #      1   2    3    4    5    6    7    8
  Page #  1 10000    0    0    0    0    0    0    0
  Page #  2 10000    0    0    0    0    0    0    0
  Page #  3 10000    0    0    0    0    0    0    0
  Page #  4 10000    0    0    0    0    0    0    0

  Page # 33    0    0    0    0    0    0    0 10000
  Page # 34    0    0    0    0    0    0    0 10000
  Page # 35    0    0    0    0    0    0    0  5434
```

Summary data is written into the database and a table is written that shows how many particles from each grid are contained in each page. Note that the total of 345,434 electron particles is consistent with 35 pages of 10,000 particles each and a final page of 5434 particles.

A.3.3.3 Conclusion

An example of normal exit from the particle generator is:

```
PGExit: closing files ...
Close Prefix=Antenna
Close Prefix=Antenna

 Exiting Particle Generator.
```

If the file ends in any other way, the calculation did not conclude properly.

A.3.4 Track Particles

Output from the particle tracker varies depending on the intended use of the particles.

Unlike the particle generator, the particle tracker tracks all existing particles within a single run, with the outermost loop being over particle species.

A.3.4.1 Initialization and Input

The output file begins with a welcome followed by a list of recognized keywords with syntaxes and meanings. When the “PREFIX” input line is found, the database is opened and the grid structure is enumerated. The particle summary information, as well as the object information, is read from the database. This includes all species defined in the database, including species automatically created for visualization.

```
RedObj: Nsurfs= 155 Nnodes= 153
```

The remaining input lines are then processed. When the “END” line is encountered, a summary of the parameters and current status is listed. A list of all species is written out. If any of the particle species are intended for visualization only, a “PL” suffix appears at the end of the species name.

The limits for particle tracking and for trajectory recording for plotting are given in grid units, with the lowest indexed corner defined by (1, 1, 1).

A.3.4.2 Particle Tracking

No output is generated during particle tracking.

```
Species   1     0 new particles. Weight: 0.0000E+00
          385621 were partially tracked. Weight: -1.4357E+06
            0 were dead. Weight: 0.0000E+00
           683 went off primary grid. Weight: -1.1261E+04
            0 were trapped. Weight: 0.0000E+00
            0 with unknown status. Weight: 0.0000E+00
```

The initial pass through each species (as in 387 pages of species 1, above) is for the purpose of initializing and categorizing each particle prior to tracking. In this case, all the particles had been tracked previously, 683 had left the computational space, and none had hit the object (which would put them in the “dead” category). As these lines were taken from an example in which particles are being used to compute space charge, the “Weight” of the particles is the sum of all the macroparticle charges divided by ε_0 (8.854×10^{-12}). If the macroparticles are used to compute steady-state space charge from trajectories or to calculate current-to-object surfaces, then each macroparticle represents a current. The weight of each macroparticle is the macroparticle current divided by ε_0. When macroparticles are being tracked to a detector, the weight reflects only the part of the current known at the detector. The actual current is computed when it leaves the computational space. When tracked for visualization only, the weight is not used and often has a value of “1” for each macroparticle.

For each species, particle tracking consists of a loop through the grids, and for each grid reading the pages containing particles that start in that grid. Particle tracking stops when the timestep time or number of timesteps is reached or when the particle strikes the object or exits the computational space. Particle status summaries are for each grid.

A.3.4.3 Conclusion

Several snippets of potentially useful information are included at the conclusion of the particle tracker. First is a summary of the total current:

```
Proces: current to object:   -5.4743E-04 amps.
    lost current(off grid): 0.0000E+00 amps.
    trapped current    : 0.0000E+00 amps.
    other current     : 0.0000E+00 amps.
```

Next is a matrix of currents split by material name and conductor number:

```
Cond.   ALUM   GOLD   Total
  1  -5.5E-04 0.0E+00 -5.474E-04
  2  0.0E+00 0.0E+00 0.000E+00
Total  -5.5E-04 0.0E+00 -5.474E-04
```

And finally a summary of currents measured timestep by timestep:

```
 Summary of current collected after 34 steps:
   ITime   time step #
   Dt    tracking time step      (seconds)
   Time   total tracking time      (seconds)
   Collected current collected at surfaces (amperes)
   Lost   current went off primary grid (amperes)
   Trapped  current in trapped orbit   (amperes)
   Other   current with unknown status  (amperes)
  Saved   true if potentials is saved

  ITime   Dt    Time   Collected  Lost   Trapped   Other  Saved
  -----   --    ----   ---------  ----   -------   -----  -----
   1  1.00E-07  1.00E-07 -9.46E-04  0.00E+00  0.00E+00  0.00E+00  T
   2  1.00E-07  2.00E-07  0.00E+00  0.00E+00  0.00E+00  0.00E+00  F
   3  1.00E-07  3.00E-07 -2.75E-04  0.00E+00  0.00E+00  0.00E+00  F
   4  1.00E-07  4.00E-07 -8.65E-04  0.00E+00  0.00E+00  0.00E+00  T
   5  1.00E-07  5.00E-07 -1.97E-03  0.00E+00  0.00E+00  0.00E+00  F
   6  1.00E-07  6.00E-07 -4.68E-03  0.00E+00  0.00E+00  0.00E+00  F
   7  1.00E-07  7.00E-07 -8.26E-03  0.00E+00  0.00E+00  0.00E+00  T
   8  1.00E-07  8.00E-07 -9.14E-03  0.00E+00  0.00E+00  0.00E+00  F
   9  1.00E-07  9.00E-07 -1.07E-02  0.00E+00  0.00E+00  0.00E+00  F
   10  1.00E-07  1.00E-06 -1.02E-02  0.00E+00  0.00E+00  0.00E+00  T
   11  1.00E-07  1.10E-06 -7.70E-03  0.00E+00  0.00E+00  0.00E+00  F
   12  1.00E-07  1.20E-06 -6.79E-03  0.00E+00  0.00E+00  0.00E+00  F
   13  1.00E-07  1.30E-06 -5.38E-03  0.00E+00  0.00E+00  0.00E+00  T
   14  1.00E-07  1.40E-06 -4.13E-03  0.00E+00  0.00E+00  0.00E+00  F
   15  1.00E-07  1.50E-06 -2.45E-03  0.00E+00  0.00E+00  0.00E+00  F
   16  1.00E-07  1.60E-06 -1.87E-03  0.00E+00  0.00E+00  0.00E+00  T
   17  1.00E-07  1.70E-06 -1.36E-03  0.00E+00  0.00E+00  0.00E+00  F
   18  1.00E-07  1.80E-06 -5.33E-04  0.00E+00  0.00E+00  0.00E+00  F
   19  1.00E-07  1.90E-06 -3.49E-04  0.00E+00  0.00E+00  0.00E+00  T
   20  1.00E-07  2.00E-06 -2.81E-04  0.00E+00  0.00E+00  0.00E+00  F
   21  1.00E-07  2.10E-06 -1.63E-04  0.00E+00  0.00E+00  0.00E+00  F
   22  1.00E-07  2.20E-06 -1.23E-03  0.00E+00  0.00E+00  0.00E+00  T
   23  1.00E-07  2.30E-06 -7.54E-03  0.00E+00  0.00E+00  0.00E+00  F
   24  1.00E-07  2.40E-06 -1.77E-02 -1.58E-01  0.00E+00  0.00E+00  F
   25  1.00E-07  2.50E-06 -1.96E-02 -2.01E-01  0.00E+00  0.00E+00  T
   26  1.00E-07  2.60E-06 -1.85E-02 -1.66E-01  0.00E+00  0.00E+00  F
   27  1.00E-07  2.70E-06 -1.50E-02 -3.56E-01  0.00E+00  0.00E+00  F
   28  1.00E-07  2.80E-06 -9.42E-03 -1.15E-01  0.00E+00  0.00E+00  T
   29  1.00E-07  2.90E-06 -5.43E-03  0.00E+00  0.00E+00  0.00E+00  F
   30  1.00E-07  3.00E-06 -3.67E-03  0.00E+00  0.00E+00  0.00E+00  F
   31  1.00E-07  3.10E-06 -2.20E-03  0.00E+00  0.00E+00  0.00E+00  T
   32  1.00E-07  3.20E-06 -1.10E-03  0.00E+00  0.00E+00  0.00E+00  F
   33  1.00E-07  3.30E-06 -5.47E-04  0.00E+00  0.00E+00  0.00E+00  F
```

The currents in this table are the sum of all ion and electron currents computed for the indicated timestep.

An example of normal termination of the particle tracker is:

```
 Q_Conductors:
      1   -6.1829E+00
      2    0.0000E+00

  Exiting Particle Tracker.
```

If the file ends in any other way, the calculation did not conclude properly.

A.4 Installed Files

The files installed by the *Nascap-2k* installer and their uses are listed in Table 41.

Table 41. Installed Files of *Nascap-2k*

FILE	DIRECTORY	USE
N2KReadMe.rtf	Nascap2k_4	Read Me file for *Nascap-2k*.
ObjectToolkit.jar	Nascap2k_4	Executable for *Object Toolkit* used to create finite-element representations of spacecraft surfaces. It also has materials editing capability. *Object Toolkit* output (in XML) contains the recipe for recreating/reassembling the object, object definition by nodes and surface elements, and material definitions.
GridTool.jar	Nascap2k_4	Executable for *GridTool* used to interactively define an arbitrarily nested cubic grid system for the space surrounding the object.
Nascap2k.jar	Nascap2k_4	Executable for *Nascap-2k* user interface. It is based on an index-tab metaphor, and contains tabs for problem selection, initial conditions, parameter specification, script writing, time-dependent results analysis, and two- and three-dimensional display of surface potentials and fields.
ObjectToolKitHelp.htm	Nascap2k_4	Online help for *Object Toolkit*.
GridToolHelp.html	Nascap2k_4	Online help for *GridTool*.
Nascap2kDocumentation.htm	Nascap2k_4	Online help for *Nascap-2k* user interface.
ObjectToolKit.bat	Nascap2k_4	Used to start *Object Toolkit* to create an object description for *Nascap-2k*. Will have a 64 in the title if the 64-bit version is installed.
GridTool.bat	Nascap2k_4	Used to start *GridTool*. Will have a 64 in the title if the 64-bit version is installed.
Nascap2k.bat	Nascap2k_4	Used to start *Nascap-2k*.
Nascap2k_OTkSpecs.xml	Nascap2k_4	File tailoring *Object Toolkit* for *Nascap-2k*.
N2kDB.dll	Nascap2k_4	C++ callable gateway to the database.
N2kDBTool.dll	Nascap2k_4	C++ callable gateway to N2kDBTool utility, a utility to examine the contents of an N2kDB database.
N2kDBTool.jar	Nascap2k_4	Executable for N2kDBTool, a utility to examine the contents of an N2kDB database.
N2kDBToolConsole.exe	Nascap2k_4	Console executable version of N2kDBTool, a utility to examine the contents of an N2kDB database.
N2kDLL.dll	Nascap2k_4	Computational modules.
NoradOrbitCalc.dll	Nascap2k_4	Needed by *Object Toolkit* for other applications.
libifcoremd.dll	Nascap2k_4	Intel Fortran file
libmmd.dll	Nascap2k_4	Windows system file
N2kScriptRunner.exe	Nascap2k_4	Executable to optionally use for long running calculations when no user interface is desired.
ObjectToolkitManual.pdf	Manuals	*Object Toolkit* manual in PDF format.
Nascap2k_Users_Manual.pdf	Manuals	This manual in PDF format.
Nascap2k_ScientificDocumentation.pdf	Manuals	Documentation of physical and numeric models embedded in *Nascap-2k*.
Example Problems	Manuals	Folder containing all the files needed to exactly

Table 41. Installed Files of Nascap-2k (continued)

FILE	DIRECTORY	USE
		reproduce the examples of Part III of this manual.
MaterialsReadMe.txt	**Materials**	Read Me file that explains how to use XML material files in directory.
***.xml**	**Materials**	Files containing material properties as measured by Utah State University in *SEE Interactive Spacecraft Charging Handbook* format. See Section 7.
image*.jpg, image*.jpg, props037.xml	**Nascap2k Documentation files**	Files needed for *Nascap-2k* user interface online documentation.
***Orbits.xml**	**Orbits**	Files used by *Object Toolkit* for other applications.
CombineGrids	**Utilities**	Folder containing CombineGrids.jar, used for combining two disjoint grids
CustomCurrentDLLTemplate	**Utilities**	Folder containing files needed to build a custom current DLL.

A.5 File Formats

The formats for the object definition, material definition, grid, and external plume files are listed below. The object definition and external plume files are in XML file format.

A.5.1 XML

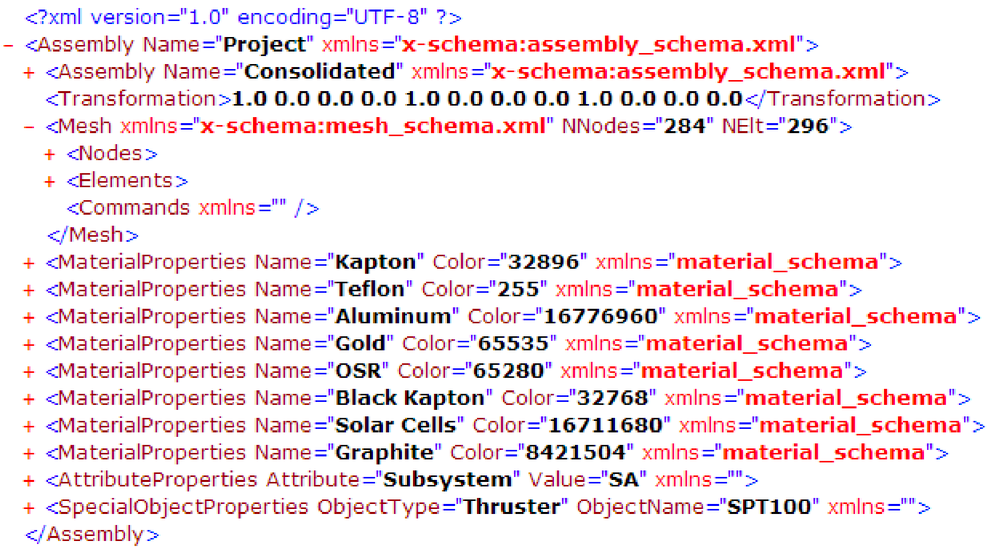
Microsoft defines XML as “Extensible Markup Language (XML) is the universal format for data on the Web … XML allows developers to easily describe and deliver rich, structured data from any application in a standard, consistent way.”

Using XML, it is easy to structure data in a way that is both logical and flexible, and easily interpreted by both human and artificial intelligence. Java and C# contain integrated, standard, World Wide Web Consortium (W3C)-compliant software to read, interpret, construct, modify, and write XML-structured data. XML parsers are also available for other languages and platforms.

Microsoft Internet Explorer is a convenient tool for displaying XML data files, allowing parts of the data tree to be expanded and collapsed. While XML files can be edited using an ordinary text editor, it is usually more convenient to use commercial software designed for that purpose. XMLShell (**http://www.softgauge.com/xmlshell/index.htm**) is an excellent aide for working with XML files.

A.5.2 Object Definition File Format

Nascap-2k uses object definition files created by *Object Toolkit*. The *Object Toolkit* output file provides the “Nodes” (points) and “Elements” (elemental surfaces) that define the geometry of the object, attributes of those surfaces, and the properties associated with the attributes. Figure 160 shows a nearly collapsed version of an *Object Toolkit* output file.



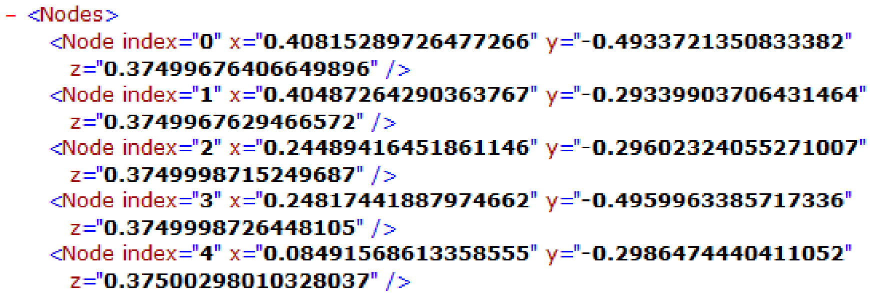
```
  <?xml version="1.0" encoding="UTF-8" ?>
- <Assembly Name="Project" xmlns="x-schema:assembly_schema.xml">
  + <Assembly Name="Consolidated" xmlns="x-schema:assembly_schema.xml">
    <Transformation>1.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0</Transformation>
  - <Mesh xmlns="x-schema:mesh_schema.xml" NNodes="284" NElt="296">
    + <Nodes>
    + <Elements>
      <Commands xmlns="" />
    </Mesh>
  + <MaterialProperties Name="Kapton" Color="32896" xmlns="material_schema">
  + <MaterialProperties Name="Teflon" Color="255" xmlns="material_schema">
  + <MaterialProperties Name="Aluminum" Color="16776960" xmlns="material_schema">
  + <MaterialProperties Name="Gold" Color="65535" xmlns="material_schema">
  + <MaterialProperties Name="OSR" Color="65280" xmlns="material_schema">
  + <MaterialProperties Name="Black Kapton" Color="32768" xmlns="material_schema">
  + <MaterialProperties Name="Solar Cells" Color="16711680" xmlns="material_schema">
  + <MaterialProperties Name="Graphite" Color="8421504" xmlns="material_schema">
  + <AttributeProperties Attribute="Subsystem" Value="SA" xmlns="">
  + <SpecialObjectProperties ObjectType="Thruster" ObjectName="SPT100" xmlns="">
  </Assembly>
```

Figure 160. Example of an *Object Toolkit* XML Output File

The enclosing tag (“Document Element”) of the file is an “Assembly,” with the name of “Project” whose mesh represents the full model that has been defined. Constituent components of this assembly (in this case, a single “Primitive”) are included as child elements of “Project.” The XML element for a constituent component (excepting primitive components) does not contain the component’s full mesh, but rather contains the directions used by *Object Toolkit* to rebuild the mesh, so that *Object Toolkit* can be used to edit the model at the component level.

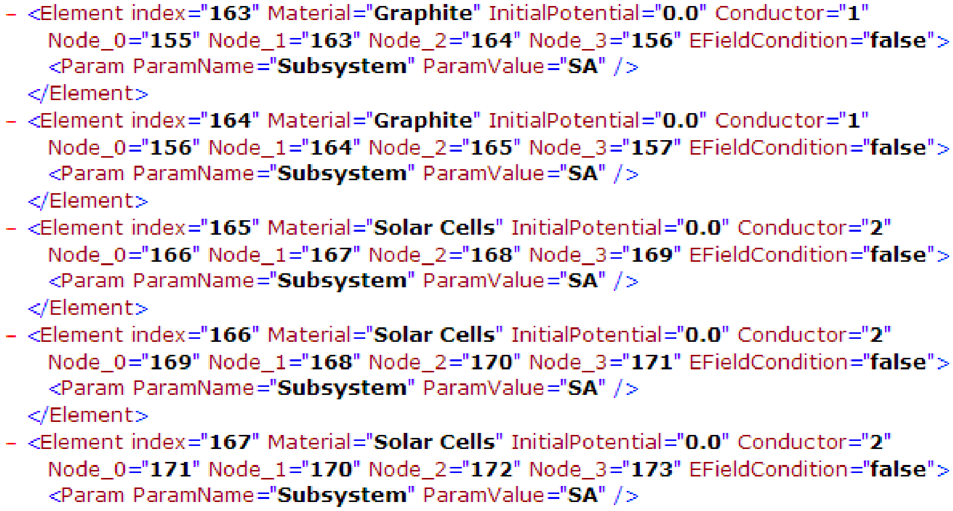
The tags of interest to applications that read the file are “Mesh” (defining the Nodes and Elements of the model), “AttributeProperties” (defining the pointing properties of portions of a spacecraft), “MaterialProperties” (defining material properties for use in *Nascap-2k*), and “SpecialObjectProperties” (used to define position and direction of thrusters and the properties of any other special components). Other tags describe the components that are combined to make the assembly; these are ignored by *Nascap-2k*, but are important to *Object Toolkit* for editing the object.

The “Mesh” tag (whose attributes include the numbers of Nodes and Elements) encloses the Nodes and Elements that define the object geometry, as well as Commands that specify additional operations to be performed when assembling the component meshes. Each Node (Figure 161) has attributes of “index” (by which it can be referenced) and “x,” “y,” and “z” (specifying its absolute position in space in meters). Figure 162 shows a series of Element tags. Each Element has attributes that include the indices of the three or four Nodes that define its geometry, and the name of its surface material. The “Subsystem” parameter (“SolarArray1” for the elements shown) is a special attribute included as a “Param” child element.



```
- <Nodes>
    <Node index="0" x="0.40815289726477266" y="-0.4933721350833382"
      z="0.37499676406649896" />
    <Node index="1" x="0.40487264290363767" y="-0.29339903706431464"
      z="0.3749967629466572" />
    <Node index="2" x="0.24489416451861146" y="-0.29602324055271007"
      z="0.3749998715249687" />
    <Node index="3" x="0.24817441887974662" y="-0.4959963385717336"
      z="0.3749998726448105" />
    <Node index="4" x="0.08491568613358555" y="-0.298647444041l052"
      z="0.37500298010328037" />
```

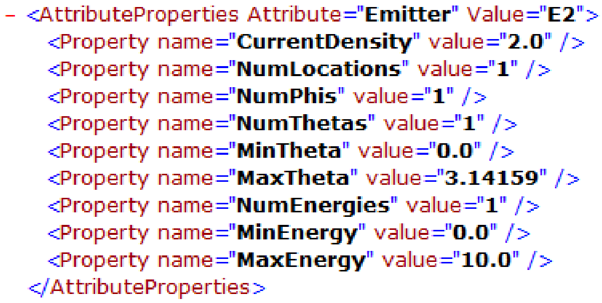
Figure 161. Series of Node Tags



```
- <Element index="163" Material="Graphite" InitialPotential="0.0" Conductor="1"
    Node_0="155" Node_1="163" Node_2="164" Node_3="156" EFieldCondition="false">
    <Param ParamName="Subsystem" ParamValue="SA" />
  </Element>
- <Element index="164" Material="Graphite" InitialPotential="0.0" Conductor="1"
    Node_0="156" Node_1="164" Node_2="165" Node_3="157" EFieldCondition="false">
    <Param ParamName="Subsystem" ParamValue="SA" />
  </Element>
- <Element index="165" Material="Solar Cells" InitialPotential="0.0" Conductor="2"
    Node_0="166" Node_1="167" Node_2="168" Node_3="169" EFieldCondition="false">
    <Param ParamName="Subsystem" ParamValue="SA" />
  </Element>
- <Element index="166" Material="Solar Cells" InitialPotential="0.0" Conductor="2"
    Node_0="169" Node_1="168" Node_2="170" Node_3="171" EFieldCondition="false">
    <Param ParamName="Subsystem" ParamValue="SA" />
  </Element>
- <Element index="167" Material="Solar Cells" InitialPotential="0.0" Conductor="2"
    Node_0="171" Node_1="170" Node_2="172" Node_3="173" EFieldCondition="false">
    <Param ParamName="Subsystem" ParamValue="SA" />
```

Figure 162. Series of Element Tags

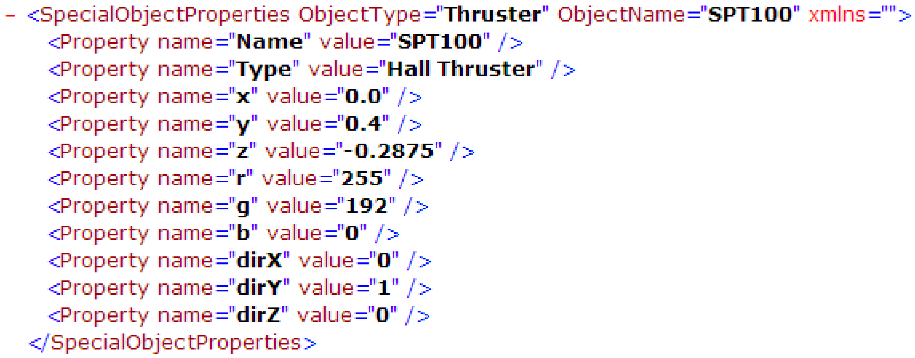
Figure 163 shows the properties to be associated with a particular value of the emitter attribute. The properties describe the current density emitted, the solid angle into which charged particles are emitted, and how many macroparticles are to be used to characterize the emission.



```
- <AttributeProperties Attribute="Emitter" Value="E2">
    <Property name="CurrentDensity" value="2.0" />
    <Property name="NumLocations" value="1" />
    <Property name="NumPhis" value="1" />
    <Property name="NumThetas" value="1" />
    <Property name="MinTheta" value="0.0" />
    <Property name="MaxTheta" value="3.14159" />
    <Property name="NumEnergies" value="1" />
    <Property name="MinEnergy" value="0.0" />
    <Property name="MaxEnergy" value="10.0" />
  </AttributeProperties>
```

Figure 163. Attribute Properties for a Specified Value of "Subsystem"

Figure 164 shows the properties to be associated with a particular instance of a "SpecialObject" of type "Thruster." The properties include the location and pointing direction, as well as the display color (in *Object Toolkit*).

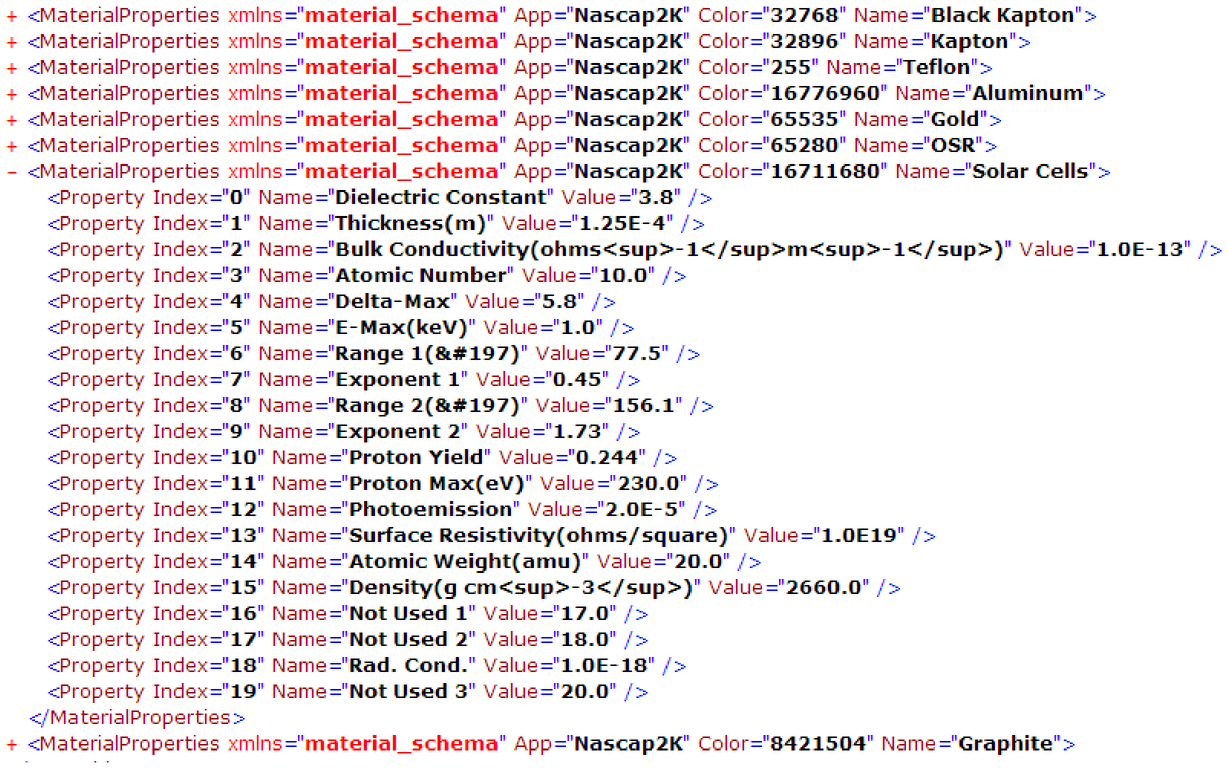


```
- <SpecialObjectProperties ObjectType="Thruster" ObjectName="SPT100" xmlns="">
    <Property name="Name" value="SPT100" />
    <Property name="Type" value="Hall Thruster" />
    <Property name="x" value="0.0" />
    <Property name="y" value="0.4" />
    <Property name="z" value="-0.2875" />
    <Property name="r" value="255" />
    <Property name="g" value="192" />
    <Property name="b" value="0" />
    <Property name="dirX" value="0" />
    <Property name="dirY" value="1" />
    <Property name="dirZ" value="0" />
  </SpecialObjectProperties>
```

Figure 164. Special Component Properties for an Instance of “Thruster”

Each material is defined by a separate “MaterialProperties” element. Each “MaterialProperties” element has three attributes. The “Name” attribute specifies the name for the material. If the “App” attribute is not present, *Object Toolkit* assumes the material is for the current application. The material color is used when displaying the object in *Object Toolkit* and *Nascap-2k.* If the “Color” attribute is not present *Object Toolkit* assigns a random color to the material. The allowed values are strings representing the defined colors (Blue, Green, Red, Yellow, Magenta, Cyan, Grey, Dark Green, Dark Red, Dark Blue, Dark Yellow, Dark Magenta, Dark Cyan, Black) and numbers specifying the RGB color definitions.

The properties of the material are specified as child elements of the “MaterialProperties” element. A property element has three attributes “Name,” “Index,” and “Value.” The “Name” attribute is the value displayed in the **Edit** dialog box for the material. The “Index” attribute contains an integer index for the property. A specific application may use either the name or the index to identify a property. *Nascap-2k* uses the “Index” to identify each property. The “Value” attribute, specifies the value for the property and must be a number.



```
+ <MaterialProperties xmlns="material_schema" App="Nascap2K" Color="32768" Name="Black Kapton">
+ <MaterialProperties xmlns="material_schema" App="Nascap2K" Color="32896" Name="Kapton">
+ <MaterialProperties xmlns="material_schema" App="Nascap2K" Color="255" Name="Teflon">
+ <MaterialProperties xmlns="material_schema" App="Nascap2K" Color="16776960" Name="Aluminum">
+ <MaterialProperties xmlns="material_schema" App="Nascap2K" Color="65535" Name="Gold">
+ <MaterialProperties xmlns="material_schema" App="Nascap2K" Color="65280" Name="OSR">
- <MaterialProperties xmlns="material_schema" App="Nascap2K" Color="16711680" Name="Solar Cells">
    <Property Index="0" Name="Dielectric Constant" Value="3.8" />
    <Property Index="1" Name="Thickness(m)" Value="1.25E-4" />
    <Property Index="2" Name="Bulk Conductivity(ohms<sup>-1</sup>m<sup>-1</sup>)" Value="1.0E-13" />
    <Property Index="3" Name="Atomic Number" Value="10.0" />
    <Property Index="4" Name="Delta-Max" Value="5.8" />
    <Property Index="5" Name="E-Max(keV)" Value="1.0" />
    <Property Index="6" Name="Range 1(&#197)" Value="77.5" />
    <Property Index="7" Name="Exponent 1" Value="0.45" />
    <Property Index="8" Name="Range 2(&#197)" Value="156.1" />
    <Property Index="9" Name="Exponent 2" Value="1.73" />
    <Property Index="10" Name="Proton Yield" Value="0.244" />
    <Property Index="11" Name="Proton Max(eV)" Value="230.0" />
    <Property Index="12" Name="Photoemission" Value="2.0E-5" />
    <Property Index="13" Name="Surface Resistivity(ohms/square)" Value="1.0E19" />
    <Property Index="14" Name="Atomic Weight(amu)" Value="20.0" />
    <Property Index="15" Name="Density(g cm<sup>-3</sup>)" Value="2660.0" />
    <Property Index="16" Name="Not Used 1" Value="17.0" />
    <Property Index="17" Name="Not Used 2" Value="18.0" />
    <Property Index="18" Name="Rad. Cond." Value="1.0E-18" />
    <Property Index="19" Name="Not Used 3" Value="20.0" />
  </MaterialProperties>
+ <MaterialProperties xmlns="material_schema" App="Nascap2K" Color="8421504" Name="Graphite">
```

Figure 165. Material Properties Specification in Object Definition File

A.5.3 *SEE Interactive Spacecraft Charging Handbook* Material Definition File

Material definitions in the XML format shown in Figure 166 can be read into *Object Toolkit* by choosing "Import SEE Handbook Materials File" on the **File** menu. The name is unrestricted, although some software has constraints. (*Nascap-2k* treats material names as four-character significant and case insensitive.) Table 42 shows the correspondence between the labels used in the file and the property names.

```
<ROOTSTUB><Materials>Material Nodes<Mkapton name="Kapton" type="Insulator" p0="3.5"
p1="0.000127" p2="1e-16" p3="5" p4="2.1" p5="0.15" p6="71.48" p7="0.6" p8="312.1" p9="1.77"
p10="0.455" p11="140" p12="0.00002" p13="10000000000000000" p14="12.01" p15="1600"
p16="17" p17="18" p18="1e-18" p19="20">Kapton</Mkapton></Materials></ROOTSTUB>
```

Figure 166. *SEE Handbook* Material Definition File for Material Kapton with Default Properties

Table 42. Correspondence Between Material Property Numbers and Names

p0	Dielectric Constant
p1	Thickness
p2	Bulk Conductivity
p3	Atomic Number
p4	Delta-Max (Secondary yield)
p5	E-Max (Secondary yield)
p6	Range 1 (Electron range)
p7	Exponent 1 (Electron range)
p8	Range 2 (Electron range)
p9	Exponent 2 (Electron range)
p10	Proton Yield (Ion induced secondary emission)
p11	Proton Max (Ion induced secondary emission)
p12	Photoemission
p13	Surface Resistively
p14	Atomic Weight
p15	Density
p16	Not used 1
p17	Not used 2
p18	Radiation-Induced Conductivity
p19	Not used 3

A.5.4 Grid File Format

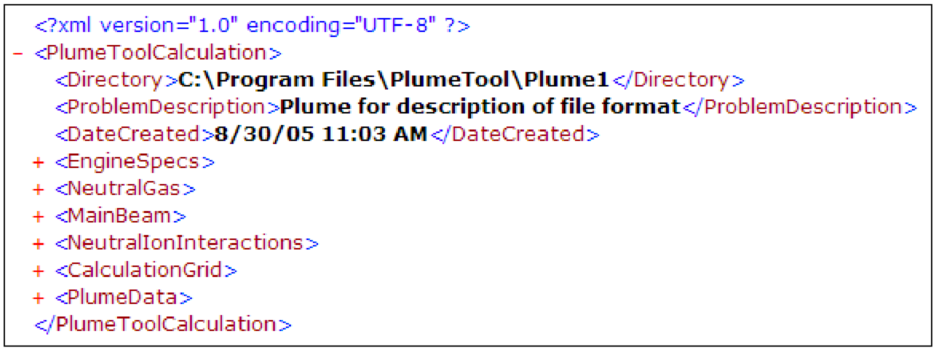
GridTool saves the grid description in a file with the name ***prefix*.grd**, using the format shown in Table 43.

Table 43. Format of Grid Definition File

LINE(S)	FIELD(S)	CONTENTS
1		Total number of grids defined
2–5		Grid 1 parameters
2	1	Grid number
2	2–4	Number of grid lines in each of the three directions
2	5	Parent grid number
2	6–11	Limits in parent grid coordinates
3	1–6	Limits in primary grid coordinates
3	7	Mesh size (m)
4	1	Mesh ratio with respect to parent grid
4	2	Mesh ratio with respect to primary grid
5		Reserved for future use (20 zeros)
6–9		Grid 2 parameters (as 2–5)
10–13		Grid 3 parameters (as 2–5)
14 on		Parameters for further grids
Last	1–3	Object size in meters
Last	4–6	Object center relative to primary grid center (m)
Last	7	Unit conversion factor

A.5.5 Plume Map File Format

The ion thruster plume map and the parameters used to specify the neutral density for charge exchange ion generation are specified in a file of the format generated by *PlumeTool*. Figure 167 shows the top level view of this XML file. The parameters used to specify the neutral density appear as text nodes or attributes within the “EngineSpecs,” “NeutralGas,” and “NeutralIonInteractions” elements. The plume map is specified within the “PlumeData” element.



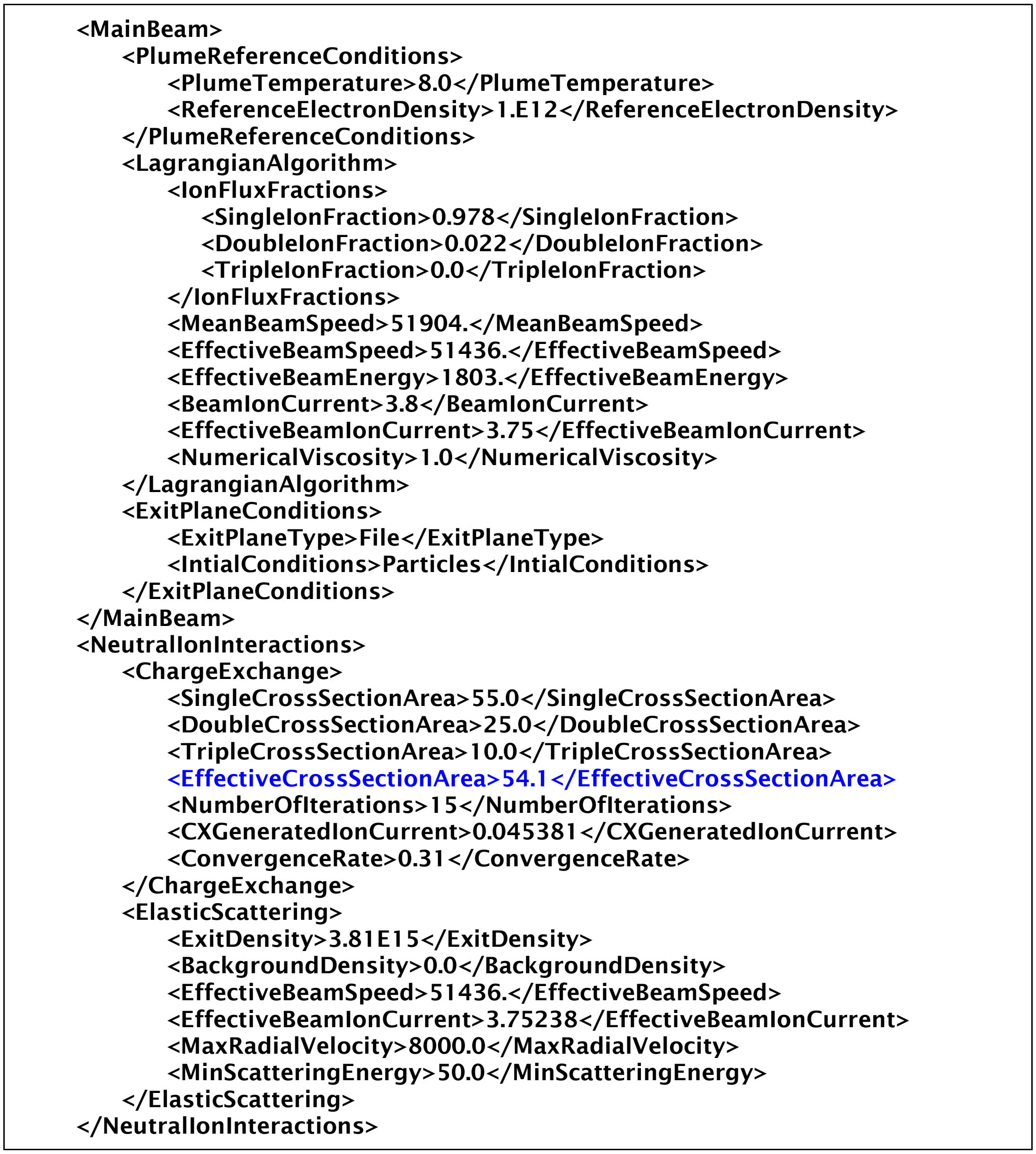
```
  <?xml version="1.0" encoding="UTF-8" ?>
- <PlumeToolCalculation>
    <Directory>C:\Program Files\PlumeTool\Plume1</Directory>
    <ProblemDescription>Plume for description of file format</ProblemDescription>
    <DateCreated>8/30/05 11:03 AM</DateCreated>
  + <EngineSpecs>
  + <NeutralGas>
  + <MainBeam>
  + <NeutralIonInteractions>
  + <CalculationGrid>
  + <PlumeData>
  </PlumeToolCalculation>
```

Figure 167. Contents of Plume Map File Shown Nearly Fully Contracted

Figure 168 and Figure 169 show the beginning part of the plume map file, fully expanded. The elements understood by *Nascap-2k* are shown in blue. All other are ignored. The tags for the elements used by *Nascap-2k* are listed and described in Table 44. The alterative units provided as attributes for four of the tags are only understood by *Nascap-2k* and are neither written nor read by *PlumeTool*. They can only be added to the file by explicitly editing the file in a text or XML editor. When both the text node and the alternative unit attribute are present within a given element, the value given in the alternative unit attribute takes precedence. All text strings are case sensitive.

```
<?xml version="1.0" encoding="UTF-8" ?>
<PlumeToolCalculation>
     <Directory>C:\Program Files\PlumeTool\Plume1</Directory>
     <ProblemDescription>Plume for description of file format </ProblemDescription>
     <DateCreated>8/30/05 11:03 AM</DateCreated>
     <EngineSpecs>
          <Geometry>
            <OuterRadius>20.0</OuterRadius>
            <InnerRadius>0.0</InnerRadius>
            <NeutralizerDistanceFromCL>29.0</NeutralizerDistanceFromCL>
            <NeutralizerHeight>9.0</NeutralizerHeight>
            <EngineRadius>20.0</EngineRadius>
          </Geometry>
          <OperatingConditions>
            <PropellantMass>131.3</PropellantMass>
            <AnodeMassFlowRate sccm="54">5.27</AnodeMassFlowRate>
            <MeanSpeed Kelvin="400">225</MeanSpeed>
            <NeutralizerMassFlowRate sccm="5.16"> 0.504
</NeutralizerMassFlowRate>
          </OperatingConditions>
          <Performance>
            <Thrust>263.0</Thrust>
            <PropellantUtilization>0.9</PropellantUtilization>
            <AnodeSpecificImpulse>4763.</AnodeSpecificImpulse>
          </Performance>
     </EngineSpecs>
     <NeutralGas>
          <Thruster>
            <Type>Holes</Type>
            <EffectiveHoleDensity>1.14E18</EffectiveHoleDensity>
            <HoleDiameter>0.00114</HoleDiameter>
            <HoleLength>7.6E-4</HoleLength>
          </Thruster>
          <Neutralizer>
            <EffectiveTemperature>810.0</EffectiveTemperature>
            <MeanSpeed>181.</MeanSpeed>
          </Neutralizer>
          <BackGround>
            <Type>Lab</Type>
            <BackgroundDensity torr="1.e-6">3.54E+16</BackgroundDensity>
          </BackGround>
     </NeutralGas>
```

Figure 168. Problem Specification Portion of Plume Map XML File, Part 1 (Tags Shown in Blue are Understood by *Nascap-2k*)



```
<MainBeam>
    <PlumeReferenceConditions>
        <PlumeTemperature>8.0</PlumeTemperature>
        <ReferenceElectronDensity>1.E12</ReferenceElectronDensity>
    </PlumeReferenceConditions>
    <LagrangianAlgorithm>
        <IonFluxFractions>
           <SingleIonFraction>0.978</SingleIonFraction>
           <DoubleIonFraction>0.022</DoubleIonFraction>
           <TripleIonFraction>0.0</TripleIonFraction>
        </IonFluxFractions>
        <MeanBeamSpeed>51904.</MeanBeamSpeed>
        <EffectiveBeamSpeed>51436.</EffectiveBeamSpeed>
        <EffectiveBeamEnergy>1803.</EffectiveBeamEnergy>
        <BeamIonCurrent>3.8</BeamIonCurrent>
        <EffectiveBeamIonCurrent>3.75</EffectiveBeamIonCurrent>
        <NumericalViscosity>1.0</NumericalViscosity>
    </LagrangianAlgorithm>
    <ExitPlaneConditions>
        <ExitPlaneType>File</ExitPlaneType>
        <IntialConditions>Particles</IntialConditions>
    </ExitPlaneConditions>
</MainBeam>
<NeutralIonInteractions>
    <ChargeExchange>
        <SingleCrossSectionArea>55.0</SingleCrossSectionArea>
        <DoubleCrossSectionArea>25.0</DoubleCrossSectionArea>
        <TripleCrossSectionArea>10.0</TripleCrossSectionArea>
        <EffectiveCrossSectionArea>54.1</EffectiveCrossSectionArea>
        <NumberOfIterations>15</NumberOfIterations>
        <CXGeneratedIonCurrent>0.045381</CXGeneratedIonCurrent>
        <ConvergenceRate>0.31</ConvergenceRate>
    </ChargeExchange>
    <ElasticScattering>
        <ExitDensity>3.81E15</ExitDensity>
        <BackgroundDensity>0.0</BackgroundDensity>
        <EffectiveBeamSpeed>51436.</EffectiveBeamSpeed>
        <EffectiveBeamIonCurrent>3.75238</EffectiveBeamIonCurrent>
        <MaxRadialVelocity>8000.0</MaxRadialVelocity>
        <MinScatteringEnergy>50.0</MinScatteringEnergy>
    </ElasticScattering>
</NeutralIonInteractions>
```

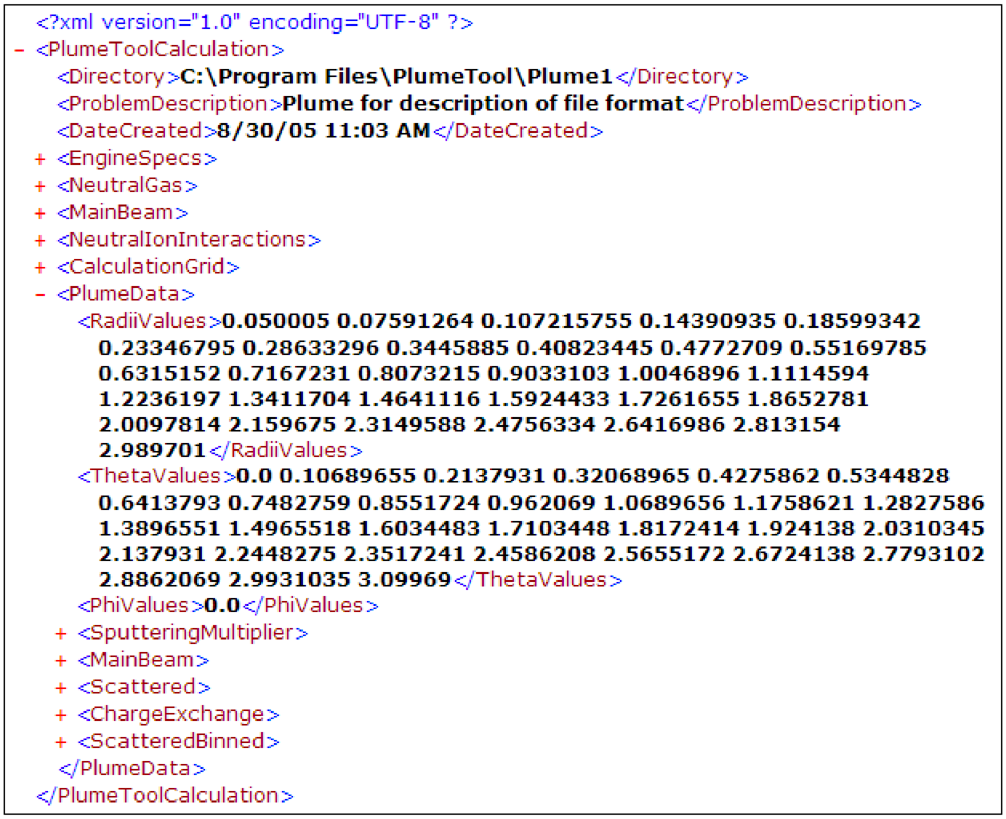
Figure 169. Problem Specification Portion of Plume Map XML File, Part 2 (Tags Shown in Blue are Understood by *Nascap-2k*)

Table 44. Problem Specification Tags in Plume Map File Understood by *Nascap-2k*

ELEMENT TAGNAME	USE	UNITS	ALTERNATIVE UNITS
EngineRadius	Radius of originating region of thruster un-ionized propellant.	cm	
PropellantMass	Atomic mass of neutral atoms from all thrusters and neutralizers	amu	
AnodeMassFlowRate	Total flow rate of propellant, both ionized and un-ionized, through thruster	mg/s	standard cubic centimeters per minute (ssm)
MeanSpeed	Temperature of un-ionized propellant. *Nascap-2k* and *Plumetool* use the mean speed differently in their computations of neutral density. In *Nascap-2k*, the use of the Kelvin attribute to specify the temperature is recommended over the use of the text node.	m/s	Kelvin
NeutralizerMassFlowRate	Flow rate of neutral atoms from neutralizer (The ions are ignored)	mg/s	standard cubic centimeters per minute (sccm)
PropellantUtilization	Fraction of propellant ionized. Used with AnodeMassFlowRate to determine flow rate of neutral atoms from thruster.		
EffectiveTemperature	Temperature of gas from neutralizer	Kelvin	
BackgroundDensity	Density (or pressure) of background gas. Use zero for space cases. The density is computed from the pressure assuming standard temperature (273 Kelvin).	m^{-3}	torr
EffectiveCrossSectionArea	Charge exchange cross section. The value from the plume map file is only read if no value appears on the **Particle**s tab.		

The plume map is specified within the “PlumeData” element. Figure 170 shows the first level nodes within the “PlumeData” element. The density values are specified on an R-θ grid in the thruster’s coordinate system. *Nascap-2k* ignores any azimuth values. The radial values are specified in meters and the angles in radians. The densities and velocities at the points specified are given within the “MainBeam,” “Scattered,” and “ChargeExchange” elements. Each of these elements encloses four text nodes: “Densities,” “Velocities,” “Description,” and “Abbreviation.” The “MainBeam” may have an optional “Neutrals” text node listing the neutral density. The density for each radius-angle pair is listed successively, with all the densities for a given radius listed before the value for the next angle. The densities are given in ions per cubic meter.

Nascap-2k reads only the “MainBeam” elements, ignoring the “Scattered” contribution as it is typically orders of magnitude smaller. Charge exchange ions are generated and tracked self-consistently within *Nascap-2k*.



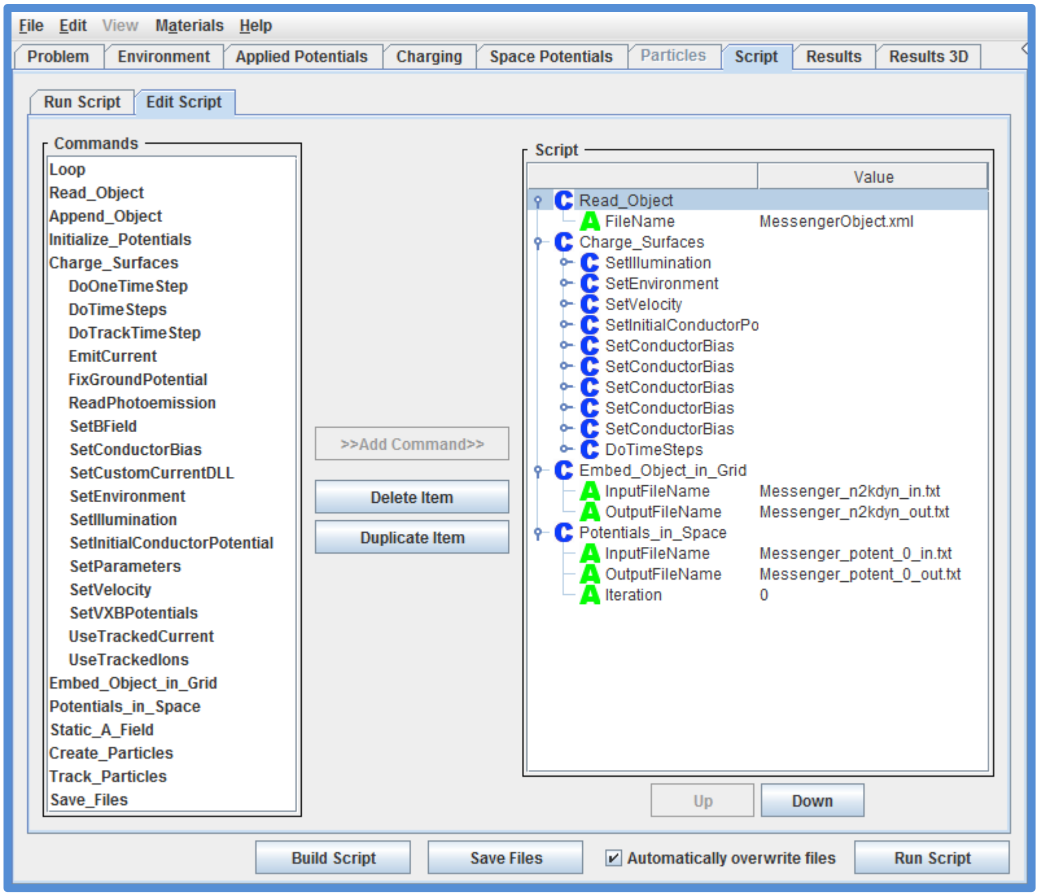
```
  <?xml version="1.0" encoding="UTF-8" ?>
- <PlumeToolCalculation>
    <Directory>C:\Program Files\PlumeTool\Plume1</Directory>
    <ProblemDescription>Plume for description of file format</ProblemDescription>
    <DateCreated>8/30/05 11:03 AM</DateCreated>
  + <EngineSpecs>
  + <NeutralGas>
  + <MainBeam>
  + <NeutralIonInteractions>
  + <CalculationGrid>
  - <PlumeData>
      <RadiiValues>0.050005 0.07591264 0.107215755 0.14390935 0.18599342
        0.23346795 0.28633296 0.3445885 0.40823445 0.4772709 0.55169785
        0.6315152 0.7167231 0.8073215 0.9033103 1.0046896 1.1114594
        1.2236197 1.3411704 1.4641116 1.5924433 1.7261655 1.8652781
        2.0097814 2.159675 2.3149588 2.4756334 2.6416986 2.813154
        2.989701</RadiiValues>
      <ThetaValues>0.0 0.10689655 0.2137931 0.32068965 0.4275862 0.5344828
        0.6413793 0.7482759 0.8551724 0.962069 1.0689656 1.1758621 1.2827586
        1.3896551 1.4965518 1.6034483 1.7103448 1.8172414 1.924138 2.0310345
        2.137931 2.2448275 2.3517241 2.4586208 2.5655172 2.6724138 2.7793102
        2.8862069 2.9931035 3.09969</ThetaValues>
      <PhiValues>0.0</PhiValues>
    + <SputteringMultiplier>
    + <MainBeam>
    + <Scattered>
    + <ChargeExchange>
    + <ScatteredBinned>
    </PlumeData>
  </PlumeToolCalculation>
```

Figure 170. Contents of Plume Map File with the First Level Under "PlumeData" Node Expanded

B. Using the *Nascap-2k* Script Runner

Nascap-2k includes a script runner that can be used for long running calculations. The executable, **N2kScriptRunner.exe**, is installed with the rest of the code in **C:\Program Files\Leidos\Nascap2k_4**.

Create the desired script on the *Nascap-2k* user interface **Script** tab as usual. Click the "Save Files" button at the bottom of the screen. At this point all the files need for *N2kScriptRunner* are generated and saved to the project directory. Among others, these include a file *prefix*Driver.xml, which contains the script commands, and several *prefix**in.txt files. After creating the files, exit the *Nascap-2k* user interface.



```
C Read_Object
    A FileName               MessengerObject.xml
C Charge_Surfaces
    C SetIllumination
    C SetEnvironment
    C SetVelocity
    C SetInitialConductorPo
    C SetConductorBias
    C SetConductorBias
    C SetConductorBias
    C SetConductorBias
    C SetConductorBias
    C DoTimeSteps
C Embed_Object_in_Grid
    A InputFileName          Messenger_n2kdyn_in.txt
    A OutputFileName         Messenger_n2kdyn_out.txt
C Potentials_in_Space
    A InputFileName          Messenger_potent_0_in.txt
    A OutputFileName         Messenger_potent_0_out.txt
    A Iteration              0
```

☑ Automatically overwrite files

Figure 171. Edit Script Subtab of Script Tab Showing "Save Files" Button at the Bottom of the Screen

N2kScriptRunner is most conveniently executed using a batch file. The content of the "bat" file should be the following single line:

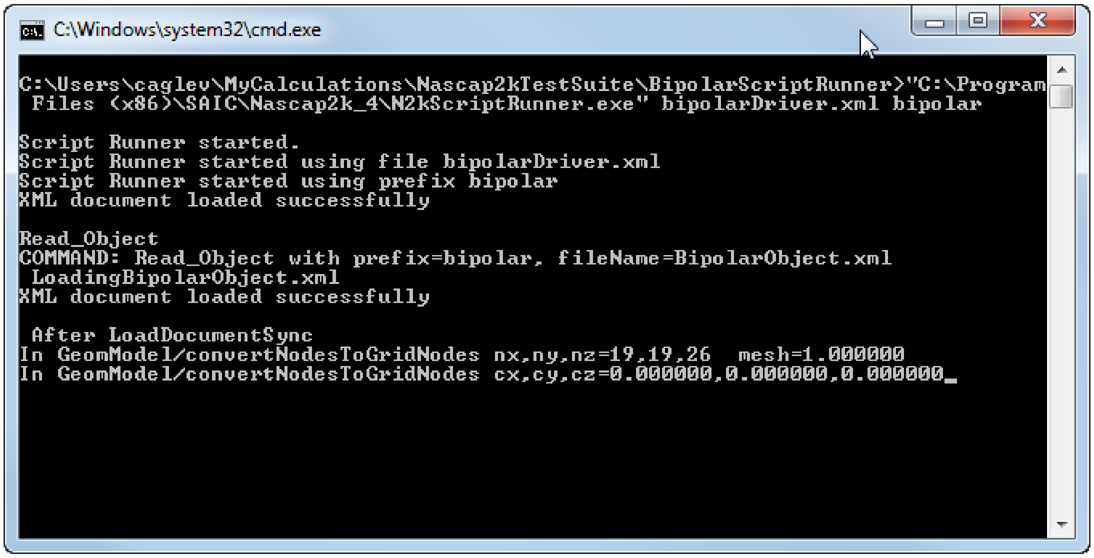
```
C:\Program Files\Leidos\Nascap2k_4\N2kScriptRunner.exe prefixDriver.xml prefix > outputfile.txt
```

where *prefix* is your project prefix, *outputfile.txt* is the desired location for the text output, and "C:\Program Files\Leidos\Nascap2k_4" is the directory in which *Nascap-2k* is installed. The name of the script file and the project prefix are supplied to the *N2kScriptRunner* as command line arguments.

Alternatively, the content of the "bat" file can include the following two lines:

```
PATH %Program Files%\Leidos\Nascap2k_4;%PATH%
N2kScriptRunner.exe prefixDriver.xml prefix > outputfile.txt
```

where *prefix* is your project prefix, *outputfile.txt* is the desired location for the text output, and "%Program Files%\Leidos\Nascap2k_4" is the directory in which *Nascap-2k* is installed.



```
C:\Users\caglev\MyCalculations\Nascap2kTestSuite\BipolarScriptRunner>"C:\Program
 Files (x86)\SAIC\Nascap2k_4\N2kScriptRunner.exe" bipolarDriver.xml bipolar

Script Runner started.
Script Runner started using file bipolarDriver.xml
Script Runner started using prefix bipolar
XML document loaded successfully

Read_Object
COMMAND: Read_Object with prefix=bipolar, fileName=BipolarObject.xml
 LoadingBipolarObject.xml
XML document loaded successfully

 After LoadDocumentSync
In GeomModel/convertNodesToGridNodes nx,ny,nz=19,19,26  mesh=1.000000
In GeomModel/convertNodesToGridNodes cx,cy,cz=0.000000,0.000000,0.000000_
```

Figure 172. Output File Showing Beginning of Execution of *N2kScriptRunner*

Once *N2kScriptRunner* has completed the calculation, the *Nascap-2k* user interface can be used to view the results.

C. Template for *Nascap-2k* Custom Current DLL

C.1 Purpose

The purpose of a "Custom Current" DLL is to calculate currents to surface elements in a manner the analyst considers more appropriate to his or her problem than the formulations built in to *Nascap-2k*'s surface charging module, N2KDLL. For example, the template contains the "EWB Plate" formulation, which is appropriate to a low Earth-orbiting spacecraft with no highly biased surface elements, and takes into account ram ions and wake effects.

C.2 Mechanics of Use

The custom current DLL is loaded dynamically by N2kDLL, which expects to find the two entry points described below. The analyst assigns the DLL an appropriate filename and specifies the name of the file, complete with its entire path, in *Nascap-2k*. The filename, with its path, is specified to N2kDLL in the SetCustomCurrentDLL script item.

C.3 Template

The template contains the C++ and project files needed to create a custom current DLL. The supported programming environment is Microsoft Visual Studio 8.

C.4 Entry Points

The DLL contains two entry points, which are called by N2kDLL.

CALLBACK setEnvironmentParams(double* den, double* te, double* ti, Vector3* objvel, double* ionamu) is called once each timestep to set the calculation parameters, which are:

- den – The first electron density of a GEO environment
- te – The first electron temperature of a GEO environment
- ti – The first ion temperature of a GEO environment
- objvel – The spacecraft velocity
- ionamu – The ion atomic mass, presently hardwired to be 16.

The analyst may hardwire additional parameters into the DLL, read parameters from a file, or otherwise obtain additional parameters.

CALLBACK getCustomCurrent(element* elem, double* I0, double* I1)

is called for every surface element at each timestep. The element structure's public member variables (listed below) are accessible to the analyst. Element public methods are NOT accessible, as the source code is not provided. (The header file **element.h** must be identical to the file used in building N2kDLL.) The analyst is responsible for calculating and returning I0 – the surface element current divided by ε_0 (=JA/ ε_0, units of Vms^{-1}), and I1 – the derivative of I0 with respect to surface potential. (Note that I1 must be non-positive.)

C.5 The Vector3 Class

The Vector3 class, implemented in Vector3.cpp, is used to encapsulate three-vectors and numerous useful methods. The analyst can easily discover these methods through inspection of the code (provided). Note that many of the Vector3 methods return pointers to new Vector3 objects; it is the responsibility of the custom DLL programmer to delete these objects.

C.6 Other Files

The **Nascap-2k/src/CustomCurrentDLLTemplate/Include** folder contains several include files, the most noteworthy of which is element.h, whose properties are described below. The file **derf.cpp** is used in the "EWB Plate" formulation and is not generally required.

C.7 Surface Element Properties

The surface element properties listed in Table 45 are accessible to the analyst via the elem->*propertyname* construct:

Table 45. Surface Element Properties

Type	Variable Name	Description
double	area	Surface element area (m^2)
double	capacitance	Surface element Capacitance/ε_0 (meters)
Vector3*	center	Location of surface element center (meters)
conductor*	conduc	Structure with info about associated conductor
int	conductorIndex	Index of the associated conductor
boolean	eFieldCondition	True if EFieldCondition for surface is “true” in the object definition file.
double	field	Normal component of electric field (V m^{-1})
boolean	fixedInsulator	True if FixedPotential for surface is “true” in the object definition file. Value is set using the “Insulator Surface Potentials” region on the **Applied Potentials** tab.
int	index	Fortran-style index of the surface element
double	initialcurrent	Current at the beginning of the timestep
double	initialPotential	Cell potential to be used in SetInitialPotentials (V)
char	materialName(32)	Name of the surface element’s material
material*	matl	Pointer to the associated material structure
double	maxpotential	Maximum potential on the object (V)
double	minpotential	Minimum potential on the object (V)
element*	next	Pointer to the next surface element to be iterated over
node*	nodes(4)	An array of pointers to the four nodes in counterclockwise order
Vector3*	normal	Unit outward normal to the surface element
double	normalfield	Normal component of electric field (V m^{-1})
double	potential	Surface element potential (V)
element*	prev	Pointer to the previous surface element iterated over
Projection	proj	Structure describing the projection of the surface element onto a plane normal to the velocity vector
Vector3*	ram	Unit vector in the velocity direction
double	speed	Magnitude of the spacecraft velocity (m s^{-1})
Vector3*	sundir	Unit vector from the spacecraft toward the sun
double	sunIntensity	Ratio of sun intensity to the usual sun intensity at 1 AU
BOOL	sunlit	True if the surface normal has a positive scalar product with the sun direction

For the node object, the only potentially useful public variable is the index. For the material object the name and the arrays of input property values (pInput) and processed values (pProps) are publicly available. (Note that the property array indices in C++ are one less than their Fortran indices.) The properties of the conductor object are all publicly accessible.

D. Disjoint Grids in *Nascap-2k*

D.1 Overview

Objects can be defined in disjoint grids and used for *Nascap-2k* calculations. The idea is that, while the grid and object models are disjoint, the objects are electrically connected, so that meaningful calculations may be performed. In the course of this description, we illustrate a simple example of such a calculation.

D.2 Defining the Objects and Grids

We start by defining each of the disjoint objects together with its grid structure in the usual way. At present, it is necessary for both outer grids to have the same mesh spacing. Using different primary grid spacings causes potentials to be both wrongly calculated and displayed. Each object should be centered in its own computational grid before starting.

For this example, we define a “Lower” object as a three-meter 6×6×6 gold cube, and an “Upper” object as a one-meter 4×4×4 aluminum cube. Both use a 0.8 meter primary grid, with a three-grid structure for the “Lower” object and a four-grid structure for the “Upper” object. Figure 173 and Figure 174 show *GridTool* pictures of these two object and grid structures.

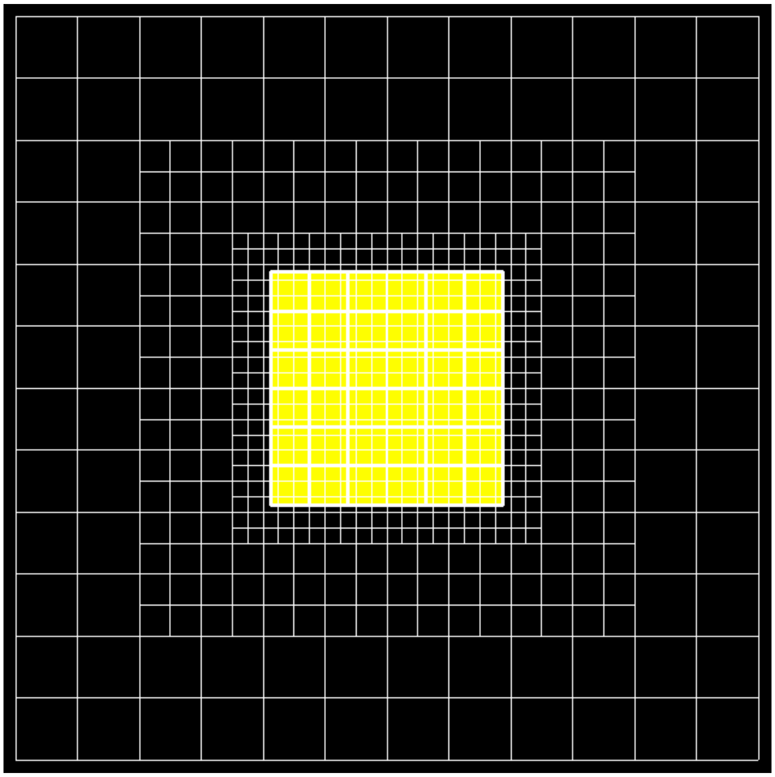


Figure 173. The “Lower” Object and Grid

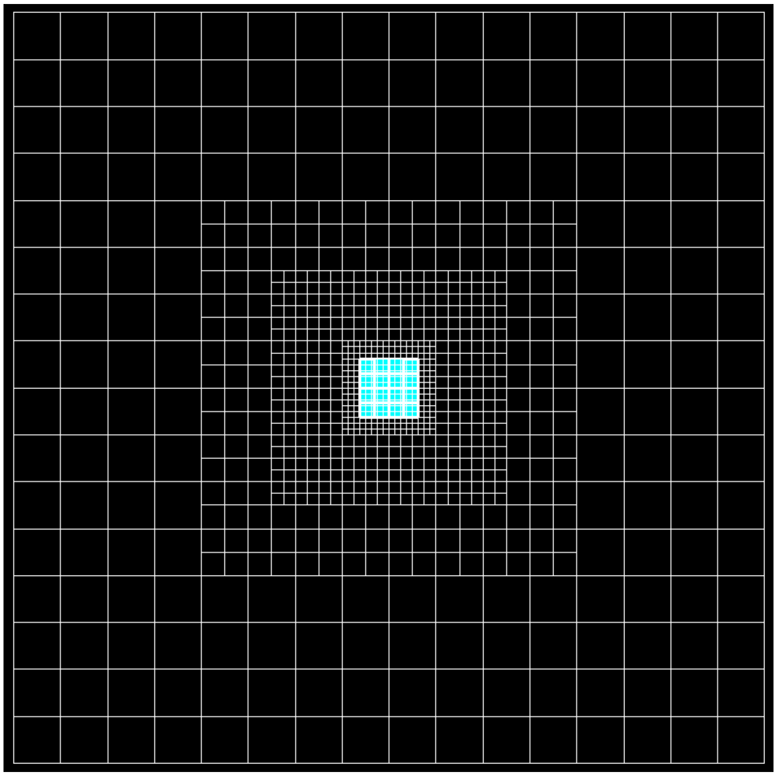
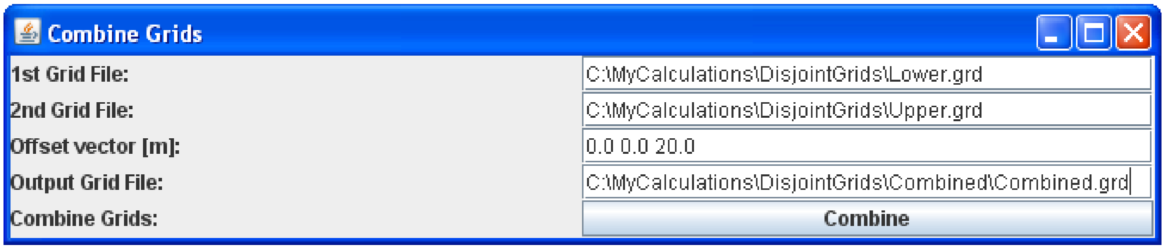


Figure 174. The "Upper" Object and Grid

D.3 Combining the Grids

The two grid files must be combined using the *CombineGrids* Java application. The jar for this application is included in the **Utilities** folder in the *Nascap-2k* installation. Figure 175 shows the *CombineGrids* user interface. The full pathnames to the primary, secondary, and combined grid structures are entered. In the "Offset Vector" field, enter the vector distance from the center of the primary grid structure to the center of the secondary grid structure. In this case, we place the "Upper" object 20 meters above (+Z) the "Lower" object. (This relatively modest distance is chosen so that the results can be easily seen in the *Nascap-2k* user interface. If more realistic multikilometer distances are used, displaying the secondary grid is difficult, and displaying both grids is impossible.)



Combine Grids

1st Grid File:	C:\MyCalculations\DisjointGrids\Lower.grd
2nd Grid File:	C:\MyCalculations\DisjointGrids\Upper.grd
Offset vector [m]:	0.0 0.0 20.0
Output Grid File:	C:\MyCalculations\DisjointGrids\Combined\Combined.grd
Combine Grids:	Combine

Figure 175. The *CombineGrids* User Interface

Clicking the "Combine" button writes out the combined grid (.grd) file. In this case, grids 1–3 are the grids of the "Lower" object, grid 4 is the primary grid of the "Upper" object, and grids 5–7 (descended from 4) are the refined grids of the "Upper" object.

D.4 Creating the Combined Project and Database

The new project and database should be created in a directory containing the new grid file (**Combined.grd**), possibly the two component objects, and no other “Combined” files. (Note that we use the prefix “Combined” in this appendix, but, of course, the actual project name is at the user’s discretion.)

Create a new project

Launch the *Nascap-2k* user interface and click the “Create New Project” button. Uncheck “Create New Folder” and click “Set Location” to place the project in the folder containing **Combined.grd**. Assign a prefix (in our case, “Combined”) to the project. Click “OK.”

Load the primary object

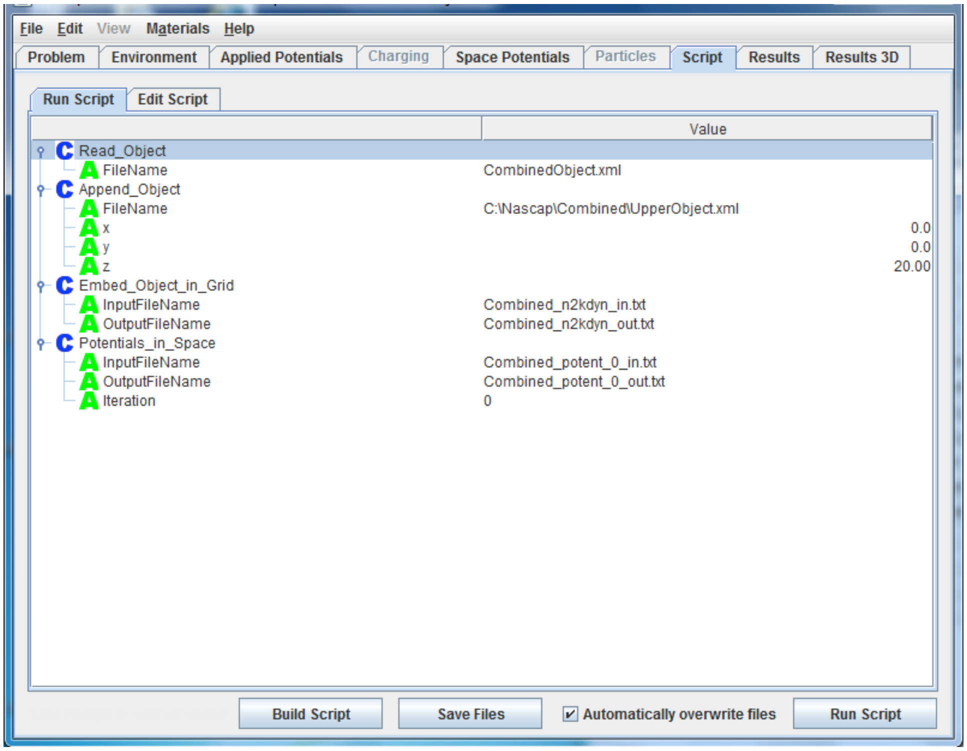
On the **File** menu select “Load Object…”. Navigate to the primary object definition file (in our case **LowerObject.xml**), select it, and click “Open.” The second object (UpperObject.xml) is added later through the script. The “Grid Status” should show the grid already loaded.

Select “Problem Type” and parameters

For this example, we select a “LEO” “Environment” and the “Analytic Space Charge” option under “Potentials in Space or Detector Analysis” as the “Problem Type.” On the **Environment** tab, set Density=10^{11} m^{-3}, Temperature=0.3 eV, B=(0., 2.5e-5, 0.) tesla (northward), V=(7500, 0, 0) (eastward). (Correspondingly, **V**×**B** is in the Z direction, which we consider upward.) Add the Oxygen species. On the **Space Potentials** tab the “Non-linear” “Charge Density Model” is selected.

Build the script

The script used to create the combined object (as it appears in the Script window) is shown in Figure 176. This can be built by adding commands to the script within the interface. Alternatively, it may be written to a file (shown in Figure 177) and loaded by selecting “Load Script” on the **File** menu. Note that the (x,y,z) coordinates in the **AppendObject** command correspond to the “Object Center Offset” displayed by *CombineGrids* and are not necessarily the same as the grid offset. The argument of the **AppendObject** command is the filename of the second object, UpperObject.xml.



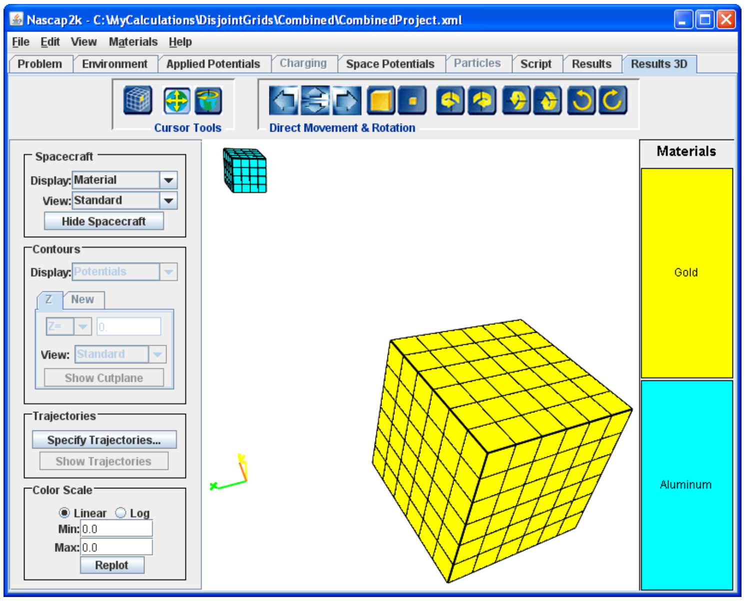
	Value
Read_Object	
FileName	CombinedObject.xml
Append_Object	
FileName	C:\Nascap\Combined\UpperObject.xml
x	0.0
y	0.0
z	20.00
Embed_Object_in_Grid	
InputFileName	Combined_n2kdyn_in.txt
OutputFileName	Combined_n2kdyn_out.txt
Potentials_in_Space	
InputFileName	Combined_potent_0_in.txt
OutputFileName	Combined_potent_0_out.txt
Iteration	0

Figure 176. Script Used to Append "Upper" Object

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<SCRIPT>
<COMMAND FileName="CombinedObject.xml" cmd="Read_Object"/>
<COMMAND FileName="C:\Nascap\Combined\UpperObject.xml" cmd="Append_Object" x="0.0"
y="0.0" z="20.0"/>
<COMMAND InputFileName="Combined_n2kdyn_in.txt"
OutputFileName="Combined_n2kdyn_out.txt" cmd="Embed_Object_in_Grid"/>
<COMMAND InputFileName="Combined_potent_0_in.txt" Iteration="0"
OutputFileName="Combined_potent_0_out.txt" cmd="Potentials_in_Space"/>
</SCRIPT>
```

Figure 177. XML Version of Script Used to Append "Upper" Object (CombinedDriver.xml)

After running the script, the combined object can be viewed on the **Results 3D** tab, as shown in Figure 178.

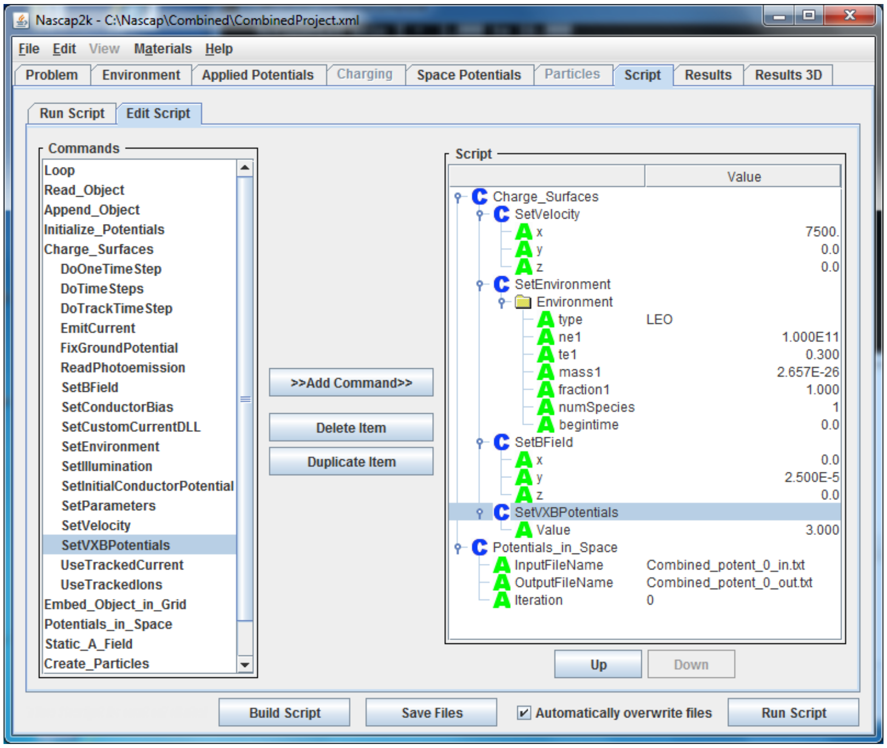

Nascap2k - C:\MyCalculations\DisjointGrids\Combined\CombinedProject.xml
File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D
Cursor Tools
Direct Movement & Rotation
Spacecraft
Hide Spacecraft
Contours
Z New
Show Cutplane
Trajectories
Specify Trajectories...
Show Trajectories
Color Scale
Replot
Materials
Gold
Aluminum

Display: Material
View: Standard
Display: Potentials
View: Standard
● Linear ○ Log
Min: 0.0
Max: 0.0

Figure 178. View of Combined Object

D.5 Calculating Potentials

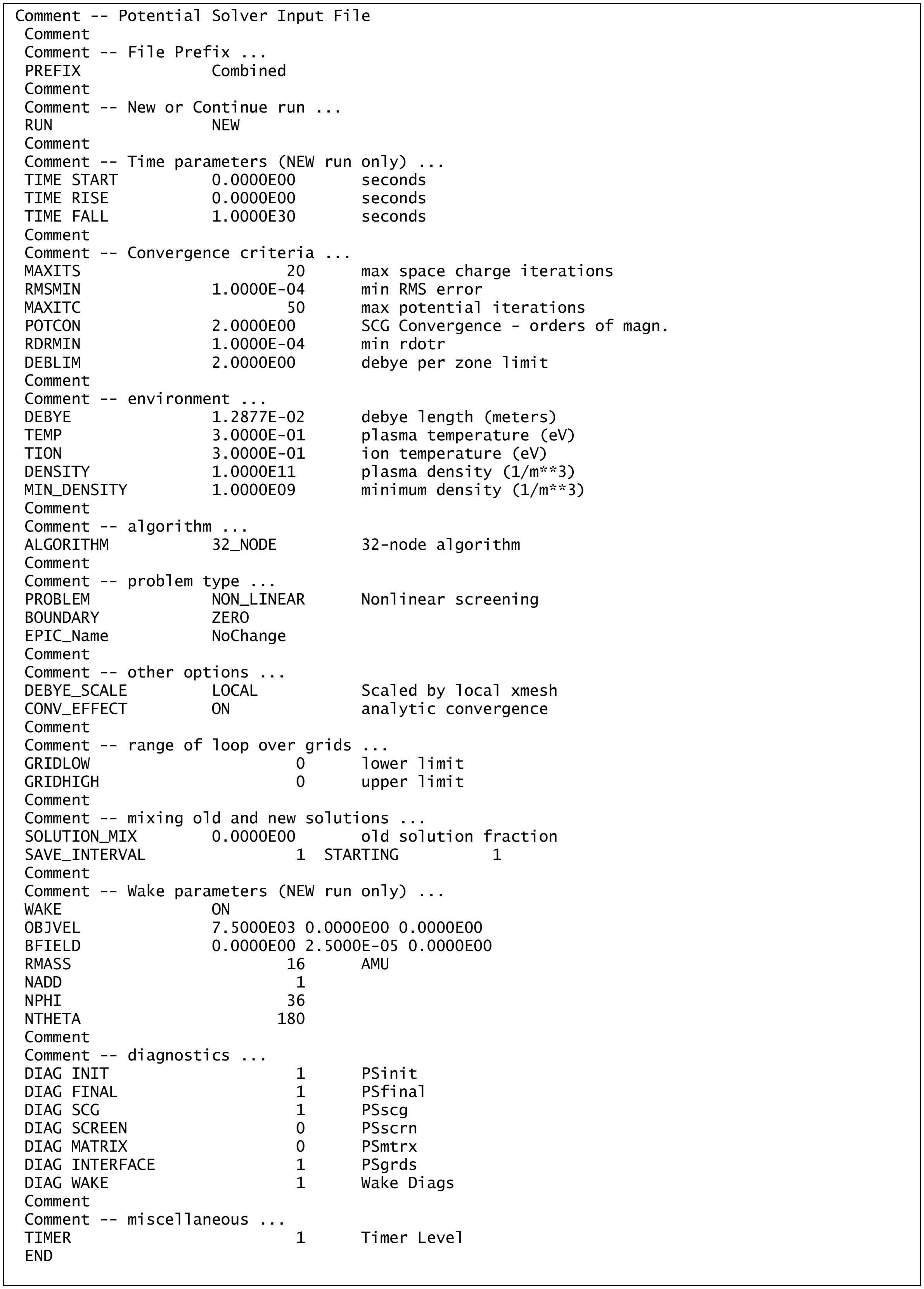
The script used for calculating potentials is shown in Figure 179. The potential solver input file is shown in Figure 180.



```
Script
                                      Value
C Charge_Surfaces
  C SetVelocity
    A x                                7500.
    A y                                  0.0
    A z                                  0.0
  C SetEnvironment
      Environment
      A type          LEO
      A ne1                         1.000E11
      A te1                            0.300
      A mass1                      2.657E-26
      A fraction1                      1.000
      A numSpecies                         1
      A begintime                        0.0
  C SetBField
    A x                                  0.0
    A y                             2.500E-5
    A z                                  0.0
  C SetVXBPotentials
    A Value                            3.000
C Potentials_in_Space
  A InputFileName     Combined_potent_0_in.txt
  A OutputFileName    Combined_potent_0_out.txt
  A Iteration         0
```

☑ Automatically overwrite files

Figure 179. Script for Calculating Potentials

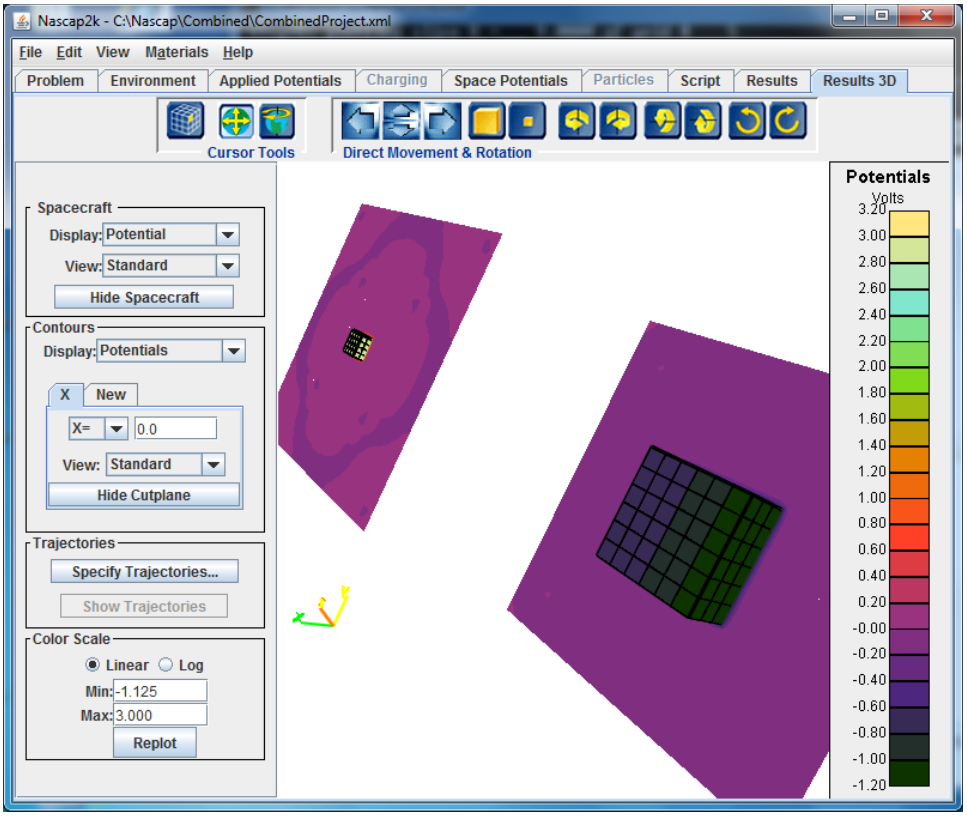


```
Comment -- Potential Solver Input File
 Comment
 Comment -- File Prefix ...
 PREFIX              Combined
 Comment
 Comment -- New or Continue run ...
 RUN                 NEW
 Comment
 Comment -- Time parameters (NEW run only) ...
 TIME START          0.0000E00       seconds
 TIME RISE           0.0000E00       seconds
 TIME FALL           1.0000E30       seconds
 Comment
 Comment -- Convergence criteria ...
 MAXITS                      20      max space charge iterations
 RMSMIN              1.0000E-04      min RMS error
 MAXITC                      50      max potential iterations
 POTCON              2.0000E00       SCG Convergence - orders of magn.
 RDRMIN              1.0000E-04      min rdotr
 DEBLIM              2.0000E00       debye per zone limit
 Comment
 Comment -- environment ...
 DEBYE               1.2877E-02      debye length (meters)
 TEMP                3.0000E-01      plasma temperature (eV)
 TION                3.0000E-01      ion temperature (eV)
 DENSITY             1.0000E11       plasma density (1/m**3)
 MIN_DENSITY         1.0000E09       minimum density (1/m**3)
 Comment
 Comment -- algorithm ...
 ALGORITHM           32_NODE         32-node algorithm
 Comment
 Comment -- problem type ...
 PROBLEM             NON_LINEAR      Nonlinear screening
 BOUNDARY            ZERO
 EPIC_Name           NoChange
 Comment
 Comment -- other options ...
 DEBYE_SCALE         LOCAL           Scaled by local xmesh
 CONV_EFFECT         ON              analytic convergence
 Comment
 Comment -- range of loop over grids ...
 GRIDLOW                      0      lower limit
 GRIDHIGH                     0      upper limit
 Comment
 Comment -- mixing old and new solutions ...
 SOLUTION_MIX        0.0000E00       old solution fraction
 SAVE_INTERVAL                1  STARTING          1
 Comment
 Comment -- Wake parameters (NEW run only) ...
 WAKE                ON
 OBJVEL              7.5000E03 0.0000E00 0.0000E00
 BFIELD              0.0000E00 2.5000E-05 0.0000E00
 RMASS                       16      AMU
 NADD                         1
 NPHI                        36
 NTHETA                     180
 Comment
 Comment -- diagnostics ...
 DIAG INIT                    1      PSinit
 DIAG FINAL                   1      PSfinal
 DIAG SCG                     1      PSscg
 DIAG SCREEN                  0      PSscrn
 DIAG MATRIX                  0      PSmtrx
 DIAG INTERFACE               1      PSgrds
 DIAG WAKE                    1      Wake Diags
 Comment
 Comment -- miscellaneous ...
 TIMER                        1      Timer Level
 END
```

Figure 180. Potential Solver Input File (Combined_potent_0_in.txt)

The “Value” in the “SetVXBPotentials” command is the maximum (most positive or least negative) potential to appear on the object. If timesteps are run, object potentials are adjusted from this initial condition based on the charging currents.

Figure 181 shows a display of the resulting object and space potentials. Note the magnetically induced potential variation on the object surface elements, and the fact that the potentials are split between the two disjoint grid structures. Figure 182 is a blow-up of the “lower” part of Figure 181, showing that potentials have been correctly calculated and plotted in this region.



Nascap2k - C:\Nascap\Combined\CombinedProject.xml

Spacecraft

Display: Potential

View: Standard

Contours

Display: Potentials

X= 0.0

View: Standard

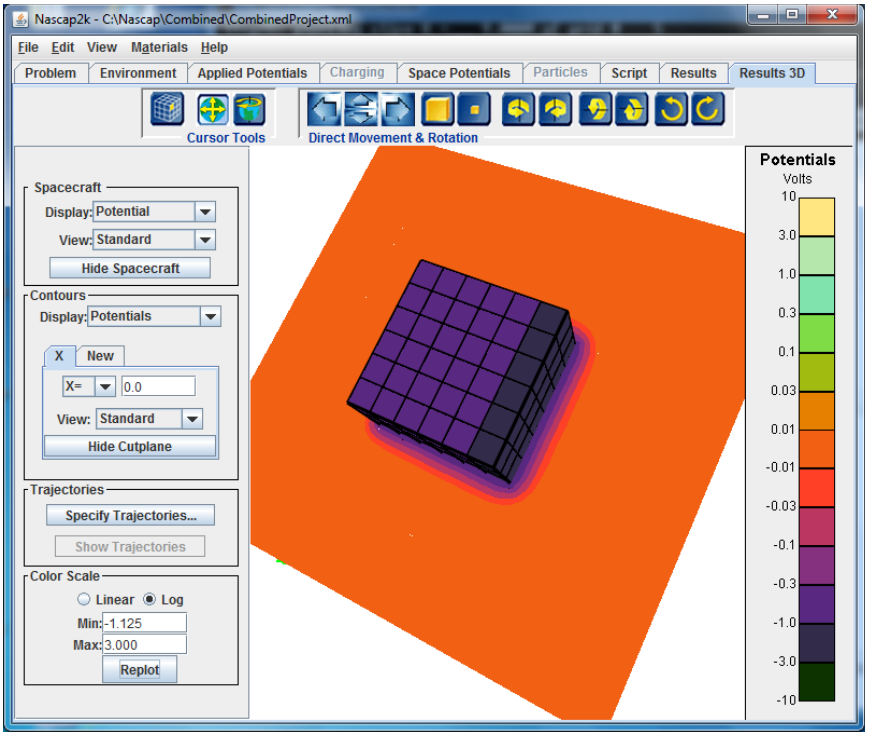
Color Scale

● Linear ○ Log

Min: -1.125

Max: 3.000

Figure 181. Results 3D Picture after Running Potential Script. Note Magnetically Induced Potential Variations on Object.


Nascap2k - C:\Nascap\Combined\CombinedProject.xml

Spacecraft

Display: Potential

View: Standard

Contours

Display: Potentials

X= 0.0

View: Standard

Color Scale

○ Linear ● Log

Min: -1.125

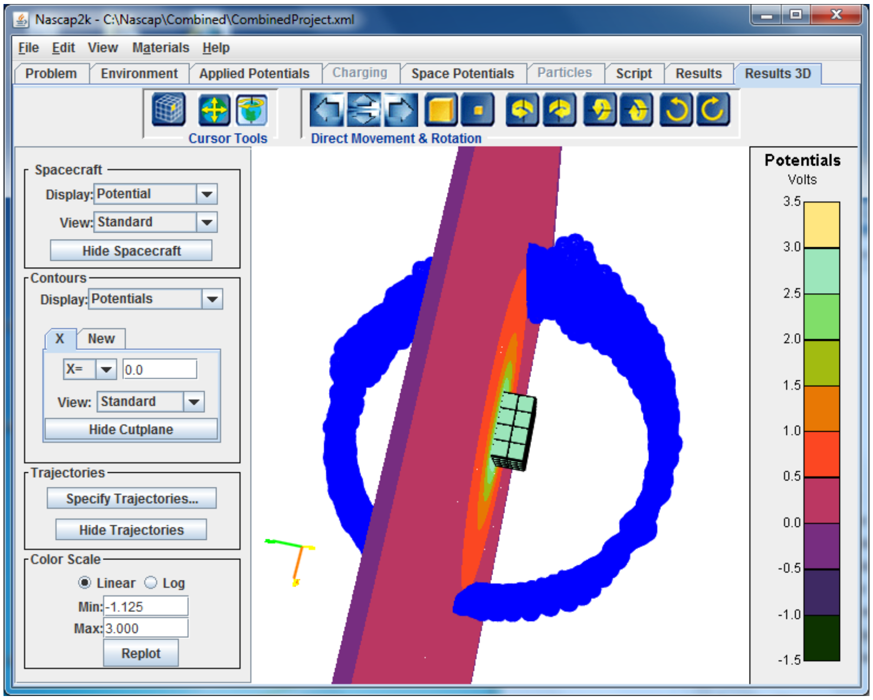
Max: 3.000

Figure 182. Expanded View of "Lower" part of Figure 181, Showing that the Potentials Have Been Correctly Calculated and Plotted

D.6 Displaying Trajectories

Particle calculations can be done, but care must be taken to ensure that the particle generation and particle tracking input files are as intended. Make sure that the particle tracking and plotting limits are large enough to include the secondary grid (note that the tracker visualization input file specifies x, y, and z limits in grid units). Because the second object was offset in the +Z direction, this is the limit that must be adjusted for both the tracking and plotting limits. Note that the default of "Track particles throughout grid" will not work because the second object is outside the limits of the first grid. Make sure that the magnetic field is included correctly in the particle tracking input file. Check the output files to make sure the charge and mass of the tracked species is correctly specified. If, after specifying trajectories, the "Show Trajectories" button is not enabling, it is most likely that the particles tracked are outside the visualization limits. Double check the output files to ensure that particles are generated and then adjust the particle tracking and plotting limits.

Figure 183 shows trajectories for electrons generated at the intersection of the 0.5 V contour with the Y = 0 plane in the secondary grid with "Contour" selected as the "Initial Particle Distribution for Trajectories." To get extended potentials the density (in the potential solver input file) was reduced to 10^6 m^3 and the potentials recomputed. The potentials in Figure 183 are on the X = 0 plane. As expected, the particles **E**×**B** drift along the potential contour, and none hit the object. Figure 184 and Figure 185 show trajectories for electrons generated at the intersection of the 0.5 V contour with the X = 0 plane in the secondary grid. The potentials in these figures are on the Y = 0 plane. In this case, the electrons whose Y-values pass through the object are rapidly collected, while the remainder bounce parallel to the Y-axis while **E**×**B** drifting.


Nascap2k - C:\Nascap\Combined\CombinedProject.xml
File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D
Cursor Tools
Direct Movement & Rotation
Spacecraft
Hide Spacecraft
Contours
X New
Hide Cutplane
Trajectories
Specify Trajectories...
Hide Trajectories
Color Scale
Replot
Potentials
Volts
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5

Spacecraft Display: Potential

View: Standard

Contours Display: Potentials

X= 0.0

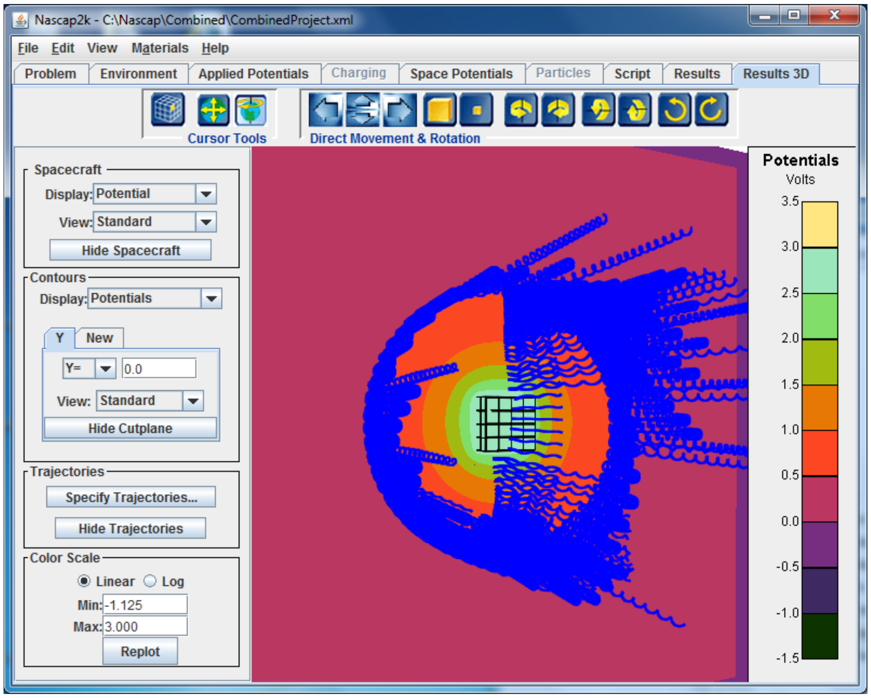
View: Standard

● Linear ○ Log

Min: -1.125

Max: 3.000

Figure 183. Trajectories of Particles Generated at the Intersection of the 0.5 V Contour and the Y = 0 Plane, which E×B Drift Along the Potential Contour


Nascap2k - C:\Nascap\Combined\CombinedProject.xml
File Edit View Materials Help
Problem Environment Applied Potentials Charging Space Potentials Particles Script Results Results 3D
Cursor Tools
Direct Movement & Rotation
Spacecraft
Hide Spacecraft
Contours
Y New
Hide Cutplane
Trajectories
Specify Trajectories...
Hide Trajectories
Color Scale
Replot
Potentials
Volts
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5

Spacecraft Display: Potential

View: Standard

Contours Display: Potentials

Y= 0.0

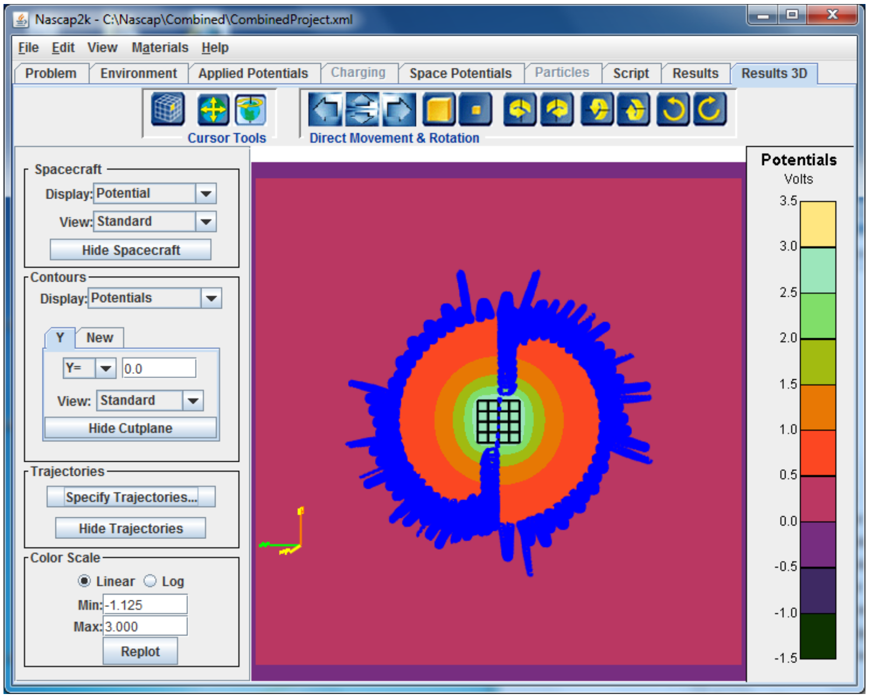
View: Standard

● Linear ○ Log

Min: -1.125

Max: 3.000

Figure 184. Trajectories of Electrons Generated at the intersection of the 0.5 V Contour and the Plane X = 0, Superimposed on Potential Contours on Y = 0 Plane Showing that Electrons Follow Magnetic Field Lines (Parallel to Y) to Hit or Miss the Object



Nascap2k - C:\Nascap\Combined\CombinedProject.xml

Spacecraft

Display: Potential

View: Standard

Contours

Display: Potentials

Y= 0.0

View: Standard

Color Scale

● Linear ○ Log

Min: -1.125

Max: 3.000

Figure 185. Trajectories of Electrons Generated at the Intersection of the 0.5 V Contour and the Plane X = 0, Superimposed on Potential Contours on Y = 0 Plane (Magnetic Field Direction Normal to Paper) Showing that Electrons that Miss the Object E×B Drift Along the Potential Contour in a Clockwise Direction until the Calculation Runs Out of Time

E. Using Plume Densities in *Nascap-2k*

Nascap-2k can use ion thruster plume densities read from an imported plume map file in a "Potentials in Space" calculation. The overall steps to perform the calculation are as follows:

1. In *Object Toolkit*, create or open an object. Make sure that one or more thrusters are defined at the correct location(s). Add any neutralizers. Save the object file.
2. If reading a two-dimensional plume map file directly into *Nascap-2k*, use either *PlumeTool* or any other tool to create a plume map with the correct format. Import the plume map into *Nascap-2k* using "Import Plume" on the **File** menu.
3. In *Nascap-2k*:
    a. Import the saved object file and define an appropriate computational grid.
    b. On the **Problem** tab, select "Potentials in Space/Consistent with Plume Ion Densities."
    c. On the **Environment** tab, define the appropriate ambient environment.
    d. On the **Applied Potentials** tab, specify potentials for all the surfaces.
    e. On the **Space Potentials** tab, choose "Plume Ion Density" charge density model. Set the appropriate "Target average error." Optionally check "Self-consistent CEX" and specify appropriate iteration sharing parameters.
    f. On the **Script** tab, generate and run the script.
    g. On the **Results 3D** tab, view the potentials.

Further details are given in the following paragraphs.

E.1 Problem Tab

The computation of “Potentials in Space” that are “Consistent with Plume Ion Densities” is only available for the “LEO or Plume” environment. If no plume map has been imported, the option is disabled.

E.2 Space Potentials Tab

The charge density model that uses ion thruster plume information is “Plume Ion Density.” If no plume map has been imported, the “Plume Ion Density” option is disabled. The charge density model used for this case is the same as the one for “Full Trajectory Ions” with the plume map ion density replacing the tracked ion density.

If “Plume Ion Density” is selected, the option to self-consistently compute the charge exchange ion density is available. If “Self-consistent CEX” is *not* selected, the ion density is the sum of the Main Beam and Charge Exchange components of the plume map. If the charge exchange *is* self-consistently computed, the ion density is the sum of the Main Beam component of the plume map and the tracked ion density. The zeroth iteration of the potential solution uses the charge exchange ion density in the plume map. The sharing of the charge density with the previous charge density for the first iteration should be zero.

E.3 Particles Tab

If “Self-consistent CEX” is selected, the **Particles** tab is enabled. On the **Particles** tab, the particles are specified to be charge exchange, the charge exchange cross section is set, and the species of particles created is set. The charge exchange current is proportional to the product of the cross section, the ion beam density, and the neutral density. The neutral density is the sum of three components: un-ionized propellant from thruster, un-ionized gas flow through neutralizers, and the background density. The parameters used to compute these terms appear in the plume map file. Additional attributes are used to specify the parameters in units appropriate to *Nascap-2k*. (See Appendix A for file format.)

E.4 Results 3D Tab

The option “Ion Charge Density” on the “Cut plane” “Display” drop-down list displays the ion charge density, computed from the plume map, or computed by particle tracking. After execution of the zeroth **Potential in Space** iteration, the “Ion Charge Density” is the sum of the Main Beam and Charge Exchange densities in the plume map. After the first **Track Particles** iteration, the “Ion Charge Density” is the tracked charge density.

E.5 Files

The text input file for “**Potentials in Space**” has a value of “Plume” for the “Problem Type.”

GLOSSARY

ATS-6: Applications Technology Satellite 6. Geosynchronous, three-axis stabilized, communications satellite launched by NASA in 1974 for research.

Attribute: Property associated with an element or XML tag. For example, *Nascap-2k* surface elements have attributes of material name, conductor number, and four pointers to nodes.

Aurora: The precipitation of charged particles in the auroral region, causing the beautiful visible displays of the Northern and Southern Lights (Aurora Borealis and Aurora Australis) that are often connected with geomagnetic substorm activity.

Auroral region: A narrow oval band around each geomagnetic pole, at about 75 degrees magnetic latitude at local noon to about 67 degrees magnetic latitude at midnight, in which auroral activity is generally most intense. It widens to both higher and lower latitudes during the expansion phase of a magnetic substorm.

Backscattered electrons: Electrons with energy (50 eV < E < primary electron energy) reflected due to coulomb scattering by the nuclei of the target material.

BEM: Boundary Element Method. A mathematical technique for solving elliptic equations (such as Laplace's equation or the Helmholtz equation) in bounded regions of two or three dimensional space. The method requires that the boundary be gridded (into line segments for two dimensional space or surface elements for three dimensional space), but does not require gridding of the area or volume. In *Nascap-2k*, it is used to establish a relationship between surface potentials and surface electric fields. (See Section 13.2 and Reference 7.)

Charge exchange: Collision between a fast ion and a slow neutral atom in which an electron transfers from the atom to the ion. Of relevance to ion plumes when the atom is low energy and the ion is high energy, such as from an ion thruster.

Charging calculation: Calculation in which surface potentials are computed from surface currents.

Charging current: Current to a surface element used in a charging calculation. Current can have both analytic and tracked components.

CHAWS: Charge Hazards and Wake Studies, an Air Force (Philips Laboratory)-sponsored experiment, which flew on the Wake Shield Facility (WSF) for the purpose of investigating high-voltage current collection within the spacecraft wake.

Child grid: A grid contained within a larger grid (its “parent” grid) for the purpose of enhanced spatial resolution. In *Nascap-2k* a child grid usually has one-half the mesh spacing of its parent.

Compatible elements: Set of surface elements such that each edge has exactly one element on its right and exactly one element on its left. *Nascap-2k* prohibits incompatible elements.

Conductor number: Number used by *Nascap-2k* to define electrical connectivity. Conductor 1 is always chassis ground. All conducting surface elements with the same conductor number have the same surface potential. Each element must have a conductor number as an attribute.

Conjugate gradient: Conjugate gradient methods are (popular) iterative methods for solving large systems of linear equations, **Ax**=**b**, where **x** is the unknown vector, **b** is the known vector, and **A** is a known square, symmetric, positive-definite matrix. Conjugate gradient methods are best suited for systems with sparse matrices.

DataBase manager: *Nascap-2k*'s library for storing and retrieving grid, element, particle, and miscellaneous information.

Debye length: Most commonly denoted as λ_D, the characteristic length for falloff of electrostatic potential in a plasma in the linear regime (originally defined in the Debye-Hűckel theory for strong electrolytes). It is given by $\sqrt{\varepsilon_o \theta / en}$ where ε_o is the permittivity in vacuum, θ is the plasma temperature, n is the plasma density, and e is the electron charge.

Differential charging: The difference in the potential of one part of the spacecraft with respect to another part of the spacecraft.

Direct-X: A Windows technology that enables higher performance in graphics and sound when playing games or watching video on computers with the Windows operating system. See http://www.microsoft.com/windows/directx/default.aspx.

DLL: Dynamic Link Library.

DMSP: Defense Meteorological Satellite Program. Series of Earth observing satellites with 101 minute, sun-synchronous, near-polar orbits at an altitude of 830 km. Some of the DMSP spacecraft have carried particle detectors that are able to measure charging events.

Double Maxwellian distribution function: An approximation representing the plasma energy distribution as the sum of two Maxwellian distributions of differing density and temperature.

***DynaPAC*:** Dynamic Plasma Analysis Code. Computer program to model dynamic behavior in plasmas developed under Air Force contract 1989–1999. Most of *Nascap-2k*'s computational abilities were originally developed for *DynaPAC*.

Electron thermal current density: Electron current density incident on one side of an imaginary surface in a thermal plasma: $en_e \sqrt{e\theta_e / 2\pi m_e}$,where e is the electron charge, n_e is the density, θ_e is the temperature, and m_e is the mass.

Element: An elemental surface defined by three (a triangle) or four (a quadrilateral) nodes. The nodes are ordered counterclockwise as viewed from an exterior point.

***EPIC*:** Electric Propulsion Interactions Code. Engineering tool to model interactions between electric propulsion effluents and spacecraft systems developed by Leidos and distributed by the SEE Program at NASA/MSFC. *EPIC* uses *Object Toolkit* to define spacecraft geometry and materials. Available from see.msfc.nasa.gov.

Finite element method: Technique for solving elliptical equations (such as Poisson's equation) in which the computational domain is divided into small elements within each of which the spatial variation of a trial function is defined by interpolation of a small number of nodal values. The solution to the discretized elliptical equation is determined by finding the set of nodal values that minimizes an integral functional of the trial function.

Floating potential: The potential of an object in a plasma at which the incident electron current, the emitted electron currents, and the ion current to the object exactly balance, so that no net current flows to the object.

Geosynchronous altitude: The altitude at which a spacecraft orbiting Earth has an orbital period of 23 hours and 56 minutes, thereby maintaining a constant latitudinal position with respect to Earth . This is approximately 6.6 Earth radii from Earth's center. Substorms, which generate kilo-electron-volt charged particles, can occur near this altitude.

GridTool: Interactive program for building an arbitrarily nested grid structure about an object. (See Section 10.)

Hybrid: In the context of computer modeling, refers to algorithms that employ a combination of particle and fluid methods to model the physics of the problem.

Ion thermal current density: Ion current density incident on one side of an imaginary surface in a thermal plasma: $e n_i \sqrt{e\theta_i / 2\pi m_i}$, where e is the electron charge, n_i is the ion density, θ_i is the temperature, and m_i the mass.

JNI: Java Native Interface, which is used in *Nascap-2k* to program the interface between interactive Java modules and computational modules written in C++ or Fortran.

Laplace's equation: The equation satisfied by electrostatic potential in vacuum: $\nabla^2 \phi = 0$. (See Poisson's equation.)

Macroparticle: An object representing a large number of ions or electrons that is tracked (as a single particle of the appropriate species) in an electromagnetic field for the purpose of calculating charge density or surface current.

Material: A name and a set of associated properties. Each surface element must have a material name as an attribute.

Mesh: A set of elements together with their defining nodes. A mesh describes the surface(s) of a spacecraft.

MESSENGER: MErcury Surface, Space ENvironment, Geochemistry, and Ranging. A NASA scientific spacecraft to Mercury launched August 2004.

MIRIAD: Module Integrator and Rule-based Intelligent Analytic Database. A Leidos proprietary model integrating technology that provides a framework for integrating a variety of physical models and their constituent data into a single executable application. The resulting application lets the user define systems of interest and perform parametric analyses on those systems. The

MIRIAD architecture manages the flow of data between the user, the database(s), and the models, enabling the user to study phenomenological relationships.

NASCAP/GEO**:** NASA Charging Analyzer Program for geosynchronous orbit environments is a set of computer codes that models the charging of spacecraft surfaces in a geosynchronous plasma in three dimensions. The codes allow for a three-dimensional, finite-element representation of a spacecraft within a 16 x 16 x 32 grid. They use orbit-limited current collection algorithms to compute the current incident to surfaces, including secondary electron emission, backscatter, and photoemission. *NASCAP/GEO* calculates the three-dimensional electric fields around the object and includes their role in limiting the emission of low energy secondary and photo electrons. *NASCAP/GEO* was developed under NASA and Air Force support, 1976–1984.

NASCAP/LEO**:** NASA Charging Analyzer Program for Low Earth Orbit. Computer program to study electrostatic interaction between a spacecraft with surfaces at high potential and a cold (0.1-1 eV), dense (10^{10}-10^{12} m^{-3}) plasma (Debye length much shorter than spacecraft dimensions).

Node: An entity representing a point in space.

Object Toolkit**:** *Nascap-2k*’s object definition tool. (See also Section 9.)

OpenGL: Widely used and supported two-dimensional and three-dimensional graphics application programming interface introduced in 1992. See **http://www.opengl.org**.

Orbit-limited current collection: Collection of current by a biased probe from surrounding plasma when the plasma density is such that the potential has a range larger than the largest impact parameter and is sufficiently well behaved so that no angular momentum barriers exist. For a sphere, this means the potential drops off no faster than r^{-2}.

OSR: Optical Solar Reflector.

Particle type: A set of species parameters (label, mass, and charge). Each macroparticle has a type. In the database, a separate particle type is created for each species used in a calculation and for each species tracked for visualization.

PATRAN**:** Popular, general purpose, three-dimensional, finite-element modeling software package distributed by MSC Software Corporation.

Photoemission: Emission of electrons by surfaces under the influence of electromagnetic radiation. In *Nascap-2k* the “electromagnetic radiation” in question is always sunlight.

Plasma: An ionized gas that is quasi-neutral, exhibits collective behavior (λ_D much less than the characteristic dimension of the plasma), and has enough particles in a Debye sphere to be a statistically valid concept (i.e., N_D=4/3 $n\pi\lambda_D{}^3$>>1).

PlumeTool**:** A program for modeling axisymmetric thruster plumes that is distributed with *EPIC*. The output is a map of ion densities and velocities. *PlumeTool* was developed by Leidos.

Poisson's equation: The general equation for electrostatic potential: $-\varepsilon_o\nabla^2\phi=\rho$, where ρ is the space charge density.

***POLAR*:** Potentials of Large Objects in the Auroral Region. A set of computer codes that model spacecraft charging, taking account of wake effects and precipitation of high-energy electrons. The codes allow for a three-dimensional, finite-element representation of a spacecraft and can use either space-charge-limited or orbit-limited current collection algorithms to compute the current incident to surfaces. It includes secondary electron emission, backscatter, and photoemission. Developed under Air Force support, 1978–1988.

Primary grid: The outermost (largest) grid in *Nascap-2k*'s arbitrarily nested grid structure. Contains the object and all subgrids.

Primitive (object)**:** An object defined by its mesh. (See also Section 9.)

RdotR: A measure of the current solution's failure to satisfy the linearized Poisson's equation. See Sections 14.1 and 14.4.

RGB color definition: An integer that specifies a color as a mixture of red, green, and blue. The RGB integer is given by the formula R + 256(G + 256B), where R, G, and B are integers between 0 and 255 inclusive.

SCATHA: Spacecraft Charging AT High Altitude. NASA spacecraft that flew a spacecraft charging experiment in the 1980s.

SCG: Scaled conjugate gradient. A simply preconditioned version of the conjugate gradient method.

Secondary electrons: Electrons with energy <50 eV emitted from surfaces under the influence of charged particle bombardment.

***SEE Interactive Spacecraft Charging Handbook*:** Interactive handbook used to assess material models, environment models, and their interactions. Uses same material and environment models as *Nascap-2k*. Available from see.msfc.nasa.gov.

SEE Program: NASA Space Environments and Effects Program at Marshall Space Flight Center.

Single Maxwellian distribution function: Distribution function appropriate to a classical gas in thermal equilibrium. Because the distribution function is simple (characterized by only a density and temperature) it is often used as an approximation to plasma distributions clearly far from thermal equilibrium.

Sheath: In a dense, motionless plasma, the region of space about a charged object from which the repelled species is excluded.

Sheath edge (Sheath Surface): Fictitious surface in space marking the boundary of the sheath. In dense, motionless plasma, the plasma thermal current times this surface area is the current collected.

SOAP: Simple Object Access Protocol: An XML-based information exchange protocol.

Space-charge-limited current collection: Collection of current by a biased probe from a surrounding plasma when the plasma density is such that the space charge of the attracted particles shields the attracting potential and thus limits the range of the potential.

SPEAR: The Space Power Experiment Aboard Rockets series of experiments was intended to develop and demonstrate technology for very high voltages in space. SPEAR-I and SPEAR-III were experiments of the type illustrated in the "Bipolar" example.

Special elements: Volume elements that are not empty or completely filled by the object or contained within a subgrid.

Substorm: Geomagnetic event during which the density of the low energy drops and a high-energy (tens of kilovolts) plasma appears. Events usually last for hours and occur every few days. More frequent and more severe events are more likely during solar maximum.

Sun intensity: Incident power per unit area (W/m^2) of incident sunlight. The value above the atmosphere at 1 AU distance from the sun is 1370 W/m^2. In *Nascap-2k* sun intensity is specified relative to this value.

Surface element: An elemental surface defined by three (a triangle) or four (a quadrilateral) nodes. The nodes are ordered counterclockwise as viewed from an exterior point.

Surface normal: Vector normal to a surface element and pointing outward. The nodes are ordered counterclockwise when viewed from the direction in which the normal points.

Tracked current: Current to a surface element computed by tracking macroparticles.

Wake: The ion depleted region of plasma behind a spacecraft moving at a speed higher than the ion thermal speed.

Vector potential: Also known as the magnetic vector potential and generally represented by "**A**". The magnetic field is the curl of **A**.

VUFF: File used by the *NX I-DEAS* TMG thermal analysis program. TMG can create an ASCII version that includes the object description.

WIND: NASA's "WIND" spacecraft was launched 1 November 1994 by a Delta rocket from Cape Canaveral. It was designed to observe the solar wind approaching Earth, from a position near the Lagrangian point L1. It is part of the International Solar-Terrestrial Physics (ISTP) Initiative.

XML: eXtensible Markup Language, a universal, simple, hierarchal text format for data.

XMLShell: XML text editor available from http://www.softgauge.com/xmlshell/index.htm.

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